Center for Crop Diversification
Martin-Gatton College of Agriculture, Food and Environment

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High Tunnel Resource Guide for Kentucky Producers

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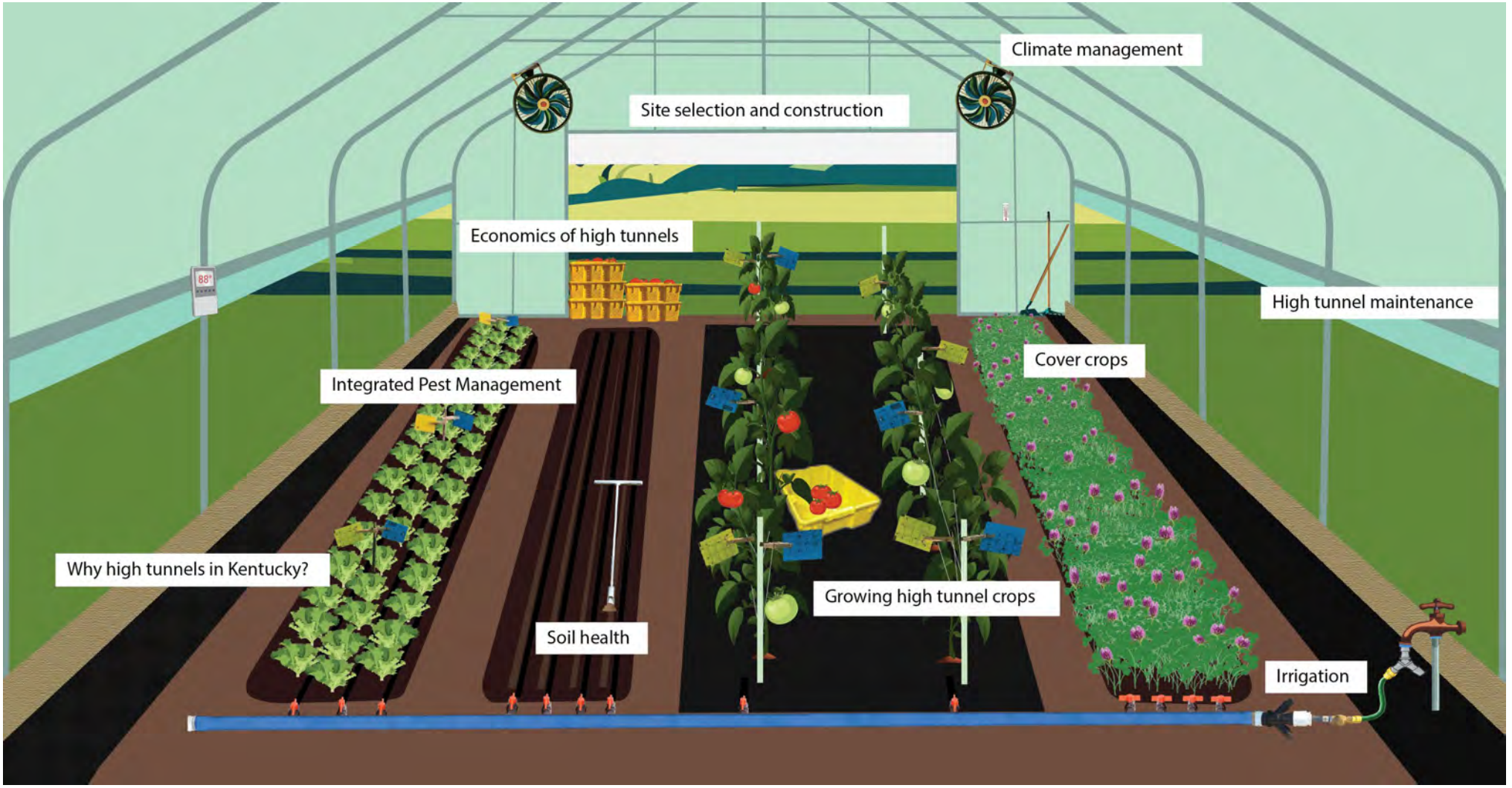

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Introduction

This high tunnel tool kit was developed to provide growers with resources and foundational skills for successful high tunnel production. The information in this guide has been sourced from cooperative extension publications, published, and unpublished research, and collaborative professional experience from the following sources:

- University of Kentucky Martin-Gatton College of Agriculture, Food and Environment
    - Department of Horticulture
    - Department of Agricultural Economics
    - Center for Crop Diversification
- Grow Appalachia - Berea College
- Kentucky Horticulture Council
- Natural Resources Conservation Service (NRCS) of the USDA
- Kentucky farmers
- Other agricultural professionals from around the state

Growing crops in high tunnels can extend the production season and result in higher quality produce. A longer growing and sales season can help growers capture premiums during times of limited availability and increase cash flow beyond traditional field production systems.

This high tunnel tool kit integrates various educational resources on a range of different topics related to high tunnels structures, production, and economics. These resources have been curated to ensure that the information contained is practical, scientifically sound, easy to use, and relevant for Kentucky high tunnel producers at various scales.

This tool kit is arranged in a tabbed format to help users find information quickly on the topics most relevant to them through the table of contents.

Navigating the Toolkit

To navigate the tool kit, users may use one or more of the following:

- The tabs from the table of contents
    - These are laid out in order of importance when considering high tunnel production for your farm.
    - This is the most comprehensive entry point that contains all topics within the tool kit
- High tunnel graphic (above) that include the interior and exterior elements of a high tunnel with clickable links relating to each visual element. Navigate by clicking the element you wish to learn about, which takes you to the appropriate chapter.
- **Resource Numbers** are available within each chapter, which will link either to a document within the toolkit **or** to an external website.
- **Back to My Spot** button will take you back to your previous place in the document.
- **All the videos** referenced in this kit are available in a **YouTube playlist** on the UK-CCD Youtube Channel
    - Channel link: https://www.youtube.com/@ccduky
    - Playlist link: https://youtube.com/playlist?list=PLTsDbxdAIJoaRCs-ta5Ctjpt9OCDzZupr&si=sdNbUg39qbtKNu8L

****Note**** for best functionality, this document should be downloaded and viewed within Adobe Reader or Acrobat rather than viewed in a web browser.

Chapter 1 - What is a High Tunnel?

A high tunnel is a structure built for the purpose of crop protection and season extension for specialty crops like fruits and vegetables that are grown in the ground. A high tunnel typically consists of the following features:

Photo 1.1 Cut flowers in a high tunnel in North Carolina. This "gothic style" structure shows the plastic covering stretched over the steel and wood frame. *Source: Brett Wolff*

Frame - A series of bows that act as structural ribs that are connected to form a "tunnel" framework.

- Galvanized steel is preferred for a high tunnel frame, though other types of metal or wood are also occasionally used.
- Notes on size:
    - The frame should be high enough for people to work comfortably underneath while managing crops.
    - High Tunnels are typically 12-36 feet wide. The length can vary, but they are often 48-96 feet long.

Covering - Over the frame, 1 or 2 layers of UV resistant greenhouse plastic film form a skin over the structure to retain heat, and shelter crops from rain and wind.

Crops Grown in the Ground - In a high tunnel, crops are grown in the ground as in traditional field production. Raised beds may be added in some cases.

Passive Solar Heat - High tunnels are generally heated through passive energy from the sun; however, heaters may be added for additional heat in colder months.

How High Tunnels are Different from Other Structures

High tunnels are related to other season extension and crop protection structures such as greenhouses, caterpillar tunnels, low tunnels, etc., but have key differences that should be considered when choosing which structure is best suited for your farm. Below are related systems and how they are different from a high tunnel:

Greenhouse

- A greenhouse can use the same frame and covering as a high tunnel, or it may be covered in glass or rigid plastic panels.
- Greenhouses are actively controlled (heated/cooled), for instance using fans, motorized louvers/sidewalls/roof vents, and/or gas, wood, or electric heaters in combination with a thermostat or other combination of sensor(s) + controller
    - While adding heaters is an option for high tunnels, it isn't required; a heated high tunnel may be treated like a greenhouse
- Key Difference – Plants are not usually grown in the ground in greenhouses. They typically have gravel, concrete, or landscape fabric floor, and plants are grown hydroponically (in gutters or float beds) or in substrate-filled containers on the floor, on benches, or hanging from the frame.
- Greenhouses are typically more expensive, permanent structures, as they require electricity to support active control features.

Caterpillar Tunnel/Hoop House

- A caterpillar tunnel or hoop house also uses similar structural elements as a high tunnel, such as bows and plastic greenhouse sheeting.
- Key Difference - These structures are not designed for year-round use - they aren't as well-braced as high tunnels for snow and wind, so are considered more seasonal structures and may not hold up to winter snow conditions in KY.
- These structures can be disassembled and/or moved more easily than a high tunnel, typically lacking doors and end walls as well as the additional bracing required by a high tunnel.

Low Tunnel

- A low tunnel uses shorter hoops to support row cover, insect netting, or specialized plastic coverings over one or more rows of a crop.
- Key Difference – Low tunnels are too low to accommodate a person working under them, so the covering must be removed to access the crop underneath for management or harvest.
- Low tunnels can be used inside of high tunnels to offer additional protection to a crop depending on the season and purpose.

Photo 1.2 Low tunnels covered with insect netting to protect melon plants. These are around 24 inches tall. High tunnels in background, left. *Source: Brett Wolff*

For more information comparing these structures, see:

Season Extension Tools and Techniques CCD-SP-03

(Resource 001)

- A five-page summary of various season extension tools and strategies for Kentucky growers with marketing and economic considerations.

Chapter 2 - Why grow in a high tunnel in Kentucky?

There are several reasons a grower might consider high tunnel production. In Kentucky, the last spring frost commonly occurs around the first week of May and the first fall frost can occur in some regions of the state as early as the last week of September. During the day, the plastic covering on a high tunnel traps heat from the sun inside the structure which can make the high tunnel several degrees warmer compared to the outside. At night, the structure is a few degrees warmer compared to the outside. The **warmer temperatures inside the high tunnel allow for the possibility of planting frost-sensitive plants earlier in spring and harvesting later into the fall compared to open field production**. In addition to heat retention, the plastic cover on a high tunnel protects crops from extreme weather, such as wind, rain, and snow.

Compared to open field production, **an effectively managed high tunnel can produce higher marketable yields per square foot for select fruit and vegetable crops**. Some crops, such as tomatoes, are well-suited to high tunnel production and can benefit more than other crops such as sweet corn or pumpkins. Therefore, high tunnel production has the potential to create high yielding, high quality produce earlier or later than the normal season which may lead to greater profit. However, it is important to **balance those potential benefits with the knowledge that high tunnels can present their own challenges.**

Photo 2.1 (top) Tunnels can get really warm—that is one of their strengths for season extension. **Photo *2.2 (bottom)*** Research at the UK Horticulture Research farm comparing high tunnel and field production. *Source: Kathryn Pettigrew*

Figure 2.1 Field vs High Tunnel Production		
	Field Production	**High Tunnel Production**
Growing Season	Limited by weather	Season extension
In-ground Production	Crops grown in ground	Crops grown in ground
Irrigation	Drip irrigation, but receives addition of rainfall	Drip irrigation required
Soil Testing	Annual soil test recommended	Soil test recommended after each cropping season
Soluble Salts	Salts naturally leach with precipitation, soluble salts test not needed	Salt buildup after several years of production; annual soluble salts test recommended
Soil Fertility	Basic fertility program based on soil test recommendations	Fertility program based on soil test recommendations with special consideration for less nutrient leaching and potential salt buildup
Airflow & Ventilation	Natural airflow around crops; crops exposed to potential wind damage	Passive ventilation with wind protection for crops
Cover Cropping	Wide range of different crops and larger equipment options; rainfall provides water for establishment	Crop selection may be different due to equipment limitations, space limitations; irrigation will be needed for establishment since rainfall is excluded
Equipment Accessibility	Readily accessible by large equipment	Often requires smaller equipment such as a walk-behind tractor or hand tools
Crop Rotation	Potentially more space for more options	Spatial limits to crop rotation
Integrated Pest Management (IPM)	Low winter temperatures aid pest and disease management; many options for pesticide products	High tunnel environment makes IPM more complex—less crop rotation, limited pesticide products, and protection of tunnel can create favorable conditions for pests and diseases

See Chapter 6, section 3 – Selecting a Crop for more information on appropriate crop selection for high tunnels.

Farmer Voice: Howard Farm

Nestled in the eastern Kentucky mountains near Vancleve, you'll find the small piece of land Jeff and Sue Howard have turned into a thriving farm through regenerative agriculture methods, hard work, and persistence. What began as a way to pay the mortgage when Jeff was laid off from the mines, is now a diversified farm with chickens, honeybees, maple syrup production, blueberries, gooseberries, black raspberries, cherry tomatoes, lettuce, onions, broccoli, and much more.

Thanks to two high tunnels and a greenhouse, they produce fruits and vegetables year-round. In particular, their hydroponic lettuce operation feeds students in the Jackson Independent school district during the school year and summer feeding program.

You can find them around eastern Kentucky at the Breathitt County Farmers Market and occasionally the Magoffin and Perry County Farmers Markets and delivering produce to Jackson Independent Schools and supplying local restaurants with farm-fresh ingredients.

Photo 2.3 & 2.4 Scenes from Howard Farm high tunnel growing operation (above) and marketing through their local farmers market (below). *Source: Jeff and Sue Howard*

General High Tunnel & Season Extension Resources

Full text versions of the resources below are available in the resources section at the end of this publication.

High Tunnel Overview (Kentucky)

CCD-SP-2 (Resource 002)

- A 7-page introduction to high tunnels including advantages and disadvantages of high tunnel production. Source: University of Kentucky Center for Crop Diversification.

Season Extension Tools and Techniques (Kentucky)

CCD-SP-3 (Resource 001)

- This 5-page publication describes potential markets for extended season production and techniques for season extension including high tunnels, floating row covers, mulches, and windbreaks. Source: University of Kentucky Center for Crop Diversification.

High Tunnel Planting Calendars and Use Guide (Kentucky)

CCD-FS-9 (Resource 003)

- A two-page guide on the principles of High Tunnel Production for season extension and instructions on how to use high-tunnel planting calendars for this purpose. Source: University of Kentucky Center for Crop Diversification.

High Tunnel Planting Calendar (Region 1—Western Kentucky)

CCD-IG-1 (Resource 004)

- A planting calendar for high tunnels in Western and far eastern Kentucky. Source: University of Kentucky Center for Crop Diversification.

High Tunnel Planting Calendar (Region 2—Central/Eastern Kentucky)

CCD-IG-2 (Resource 005)

- A planting Calendar for high tunnels in Central and Eastern KY. Source: University of Kentucky Center for Crop Diversification.

High Tunnel Planting Calendar (Region 3—Eastern Kentucky)

CCD-IG-3 (Resource 006)

- A planting calendar for high tunnels in Eastern Kentucky. Source: University of Kentucky Center for Crop Diversification.

Marketing Advantages

High Tunnel Economics (Kentucky)

CCD-FS-15 (Resource 007)

- This 4-page publication gives an overview of different variables like crop yield, price, market type, construction cost estimates, production costs, and others that those considering high tunnels should consider. Source: University of Kentucky Center for Crop Diversification.

See Chapter 3– Identify your market for more information on high tunnel economics

Other Benefits

High Tunnel Management for Beginners

(Resource 008)

- A 2-hour recorded webinar introducing high tunnels, season extension (0:00-11:00), high tunnel management (11:00-54:45), and integrated pest management for new high tunnel farmers(54:45-end). Source: University of Kentucky Vegetable Crops Extension & Research

Photo 2.5 (left) A producer stands next to a crop of high tunnel tomatoes**.** ***Photo 2.4 (right)*** While not quite a pot of gold at the end of the rainbow, managed correctly and with strategic marketing, a high tunnel can be a profitable enterprise. *Source: Chris McKenzie & Kathryn Pettigrew*

Chapter 3 - The Economics of High Tunnel Production

Before committing to a high tunnel, it is important to consider the **costs of building and maintaining it**. You should also consider **how much money you can potentially earn from your high tunnel**. This will help you decide if a high tunnel is a good for your operation. Begin by asking yourself:

- Why are you building a high tunnel? (i.e. season extension, product quality).
- Do you have a market for your products?
    - What are the prices you can expect in this market?
    - How much product can you sell in that market and when?
- How much will it cost to grow the products for those markets?

Just like growing in the field, high tunnels have both advantages and costs. You may be able to produce crops earlier and later in the season or with a higher quality compared to growing them in the field.

In addition to the upfront cost of the high tunnel structure, note the **'hidden' cost of other expenses of high tunnel production**. These may include:

- Replacing the plastic and other periodic structural maintenance
- Addressing salt build up in the soil due to lack of rainfall
- Additional labor and materials for managing the climate in a high tunnel and for growing outside the "normal" growing and labor season
- Potential storm damage – materials and repairs
- Potential requirements for additional crop management and pest control methods compared to open field production
- Potential need for specialized tools and equipment to address unique high tunnel production challenges (e.g. smaller soil preparation or cultivation equipment that can be used inside the tunnel – some full-size tractors and/or implements may not fit)
- Additional post-harvest storage/handling and food safety considerations depending on crops grown and infrastructure already present

If possible, review prior years' business records to determine if growing in a high tunnel will be a good fit for your business. If you do not have business records, there are many resources below that can help you think through the costs and benefits of high tunnel production. Regardless of whether you are a beginning farmer or have an established farm business, **recognizing and calculating potential revenue (money made) and costs ahead of time allows you to make an informed business decision.**

For the past 15 years funding has been available through the NRCS EQIP program to provide cost-sharing for high tunnels. This could be something you consider along with other resources below.

Financial considerations before constructing a high tunnel

Photo 3.1 Selling local product outside the normal season can command a higher premium and high tunnels can help produce higher quality products, but don't assume that "if you grow it, they will come." Marketing planning should be as important as production planning. *Source: Kathryn Pettigrew*

High Tunnel Economics (Kentucky)

CCD-FS-15 (Resource 007)

- This 4-page publication from the University of Kentucky Center for Crop Diversification gives an overview of different variables like crop yield, price, market type, construction cost estimates, production costs, and others that those considering high tunnels should consider.

High Tunnels: Using Low-Cost Technology to Increase Yields, Improve Quality and Extend the Season (New York)

(Resource 009)

- This 77-page publication from Cornell University includes case studies of several farms with enterprise budgets for tomatoes, greens, sweet cherries and cockscomb grown in tunnels. It also discusses other high tunnel (and low tunnel) cost considerations throughout the publication. This resource provides different structure design options.
- https://www.sare.org/resources/high-tunnels/

High Tunnel Multiple Product Vegetable Farm Budget Example

(Resource 010)

- This interactive spreadsheet from Iowa state extension provides estimated costs and returns for a multi-product High Tunnel production system. You should replace the values in the sheet with your own values for the most accurate results. The sheet points out some of the often "hidden" costs of high tunnel production including irrigation costs, water testing and production labor.

Horticulture BizQuiz

(Resource 011)

- This interactive online tool from the University of Kentucky Center for Crop Diversification prompts you to think about how much land, labor, and capital you have to contribute to an operation. While it is not high-tunnel specific, it will help you think about how many resources you have to contribute to your potential operation.

Identify your market

What to Think About Before You Plant (Kentucky)

CCD-FS-02 (Resource 012)

- This 11-page publication from the University of Kentucky Center for Crop Diversification is not high tunnel specific, but provides exercises, tables, and suggestions for identifying what kind of market you want to pursue. The publication encourages the reader to start with the customer and work backward to building a production system.

Photo 3.2 (left) Wholesale and auction markets allow you sell more product, but at a lower per-unit price**.** ***Photo 3.3 (right top)*** Establishing your own retail market can help you retain more of your product's value, but they come with additional costs. ***Photo 3.4 (right bottom)*** Farmers markets are very popular for marketing specialty crops, but they may not be open during key windows for high tunnel producers. *Source: Brett Wolff & Lexi Gardner (3.4)*

Budgets for Specific High Tunnel Crops

There are numerous High-Tunnel crop budgets available to help you plan out the costs and potential returns for your enterprise. We have provided some examples below, but we always recommend checking with local and regional extension services to see if new or updated budgets are available for the crops you want to to grow.

Photo 3.5 Harvest, packing, storing, and transporting the product are important costs to keep in mind as you develop your plan. Budgets can help account for all these costs *Source: Kathryn Pettigrew*

High Tunnel Leafy Greens & Herbs (Kentucky)

CCD-CP-60 (Resource 013)

- This 5-page publication from the University of Kentucky Center for Crop Diversification discusses both Marketing and Production of leafy greens and herbs in high tunnels. It discusses some of the economic considerations for growing in high tunnels like labor and structure costs and some specific things to consider when growing leafy greens and herbs like markets, yields, and harvest.

Sample Pepper High Tunnel Budget using Plasticulture (Pennsylvania)

(Resource 014)

- This three-page publication from Penn State Extension provides a provides a table with suggested typical costs and returns for producing peppers on plasticulture in a high tunnel. You can also enter your own values in the document to accurately track your own costs if they are different from the suggestions.

Sample Cucumber High Tunnel Budget Growing in Pots (Pennsylvania)

(Resource 015)

- This three-page publication from Penn State Extension provides a provides a table with suggested typical costs and returns for producing cucumbers in pots in a high tunnel. You can also enter your own values in the document to accurately track your own costs if they are different from the suggestions.

Sample Tomato High Tunnel Budget using Plasticulture (Pennsylvania)

(Resource 016)

- This three-page publication from Penn State Extension provides a provides a table with suggested typical costs and returns for producing tomatoes on plasticulture in a high tunnel. You can also enter your own values in the document to accurately track your own costs if they are different from the suggestions.

Chapter 4 - Site Selection, Design, and Construction

If you have assessed the costs and benefits of high tunnel production and decided that owning and operating a high tunnel is the best direction for you, there are several more steps to take before you can begin growing crops. Site selection is an important next step as it can strongly affect the longevity of the high tunnel structure, the amount of maintenance that will be required, as well as long-term production success.

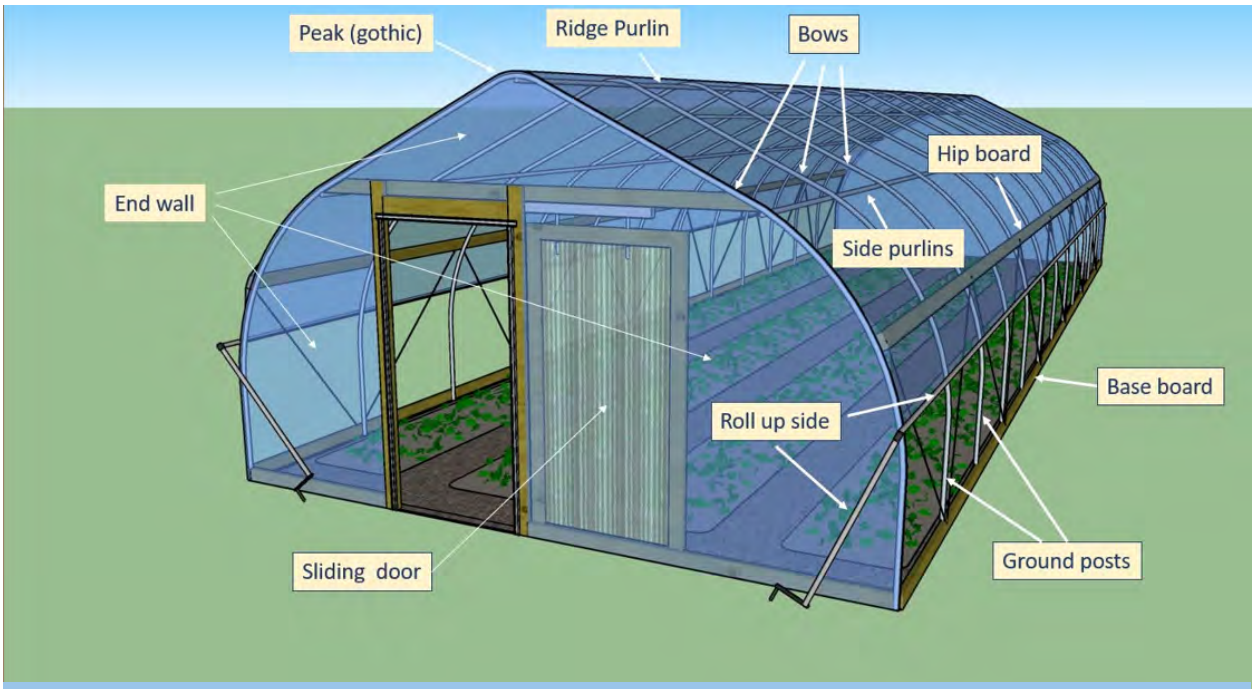

Figure 4.1 An illustration of a high tunnel with all key parts of the structure labelled. *Source: Grow Appalachia*

High Tunnel Management for Beginners (Resource 017)

- This is a video from University of Kentucky Vegetable Extension Specialist that discusses site selection, design, and construction options.

Orientation

When thinking about which direction to orient your high tunnel, **consider both sun and wind**. Kentucky is south of the 40-degree latitude line, so the general guidance for sun exposure is to **layout a high tunnel from north-to-south** to minimize shading and ensure a more even distribution of sunlight throughout the course of a day. However, those wishing to prioritize fall/winter/Spring production may choose an east-to-west orientation, which helps to maximize sunlight exposure during low-light months. Orienting a high tunnel **perpendicular to prevailing winds can offer the benefit of helpful airflow through open side walls, improving ventilation**. Other factors to

consider are sun exposure related to topography, trees, existing structures, and other features that would create shade. Nearby trees or structures may also create debris, especially in high winds, that could puncture plastic or damage the structure.

Photo 4.1 *(left)* Roll-up sidewalls allow for ventilation of humid warm air—especially if you build so that prevailing winds can blow through them. ***Photo 4.2*** *(above)* "Haygrove" style tunnels have high sidewalls for maximum ventilation. *Source: Kathryn Pettigrew*

High Tunnel Site Selection (Utah)

(Resource 018)

- This 4-page publication from Utah State University discusses the different factors of proper site selection.

High Tunnel System

(Resource 019)

- This job sheet from NRCS provides guidance on what a high tunnel can and cannot be used for, guidance on layout and location, and practices for preparing the site for high tunnel construction. Although many aspects are applicable for most new high tunnel growers these resources are aimed at growers who received NRCS cost share.

Access to electricity and water

Although electricity is not necessary for high tunnel production, it may be useful and is essential for designs that include two plastic layers with an inflation blower. Water for irrigation of crops is necessary. Make sure you have access to nearby water and a plan for *how* to access that water.

For more *information* on irrigation, see Chapter 6.

Photo 4.3 *(above)* You might choose to have frost-free hydrants installed in each tunnel. ***Photo 4.4*** *(below)* If you have existing irrigation, it may be more economical to run above ground supply lines to your tunnels *Source: Chris McKenzie & Kathryn Pettigrew*

Soil type and drainage

Ideally, a high tunnel should not be positioned on a slope or in a low spot where flooding or standing water is likely. Think about past weather events on your farm and where there have been issues. It may be necessary to install additional drainage to divert water. Re-grading the site prior to construction may also be useful to address drainage concerns, however care should be taken to preserve topsoil if using this strategy. Soil testing may be used to evaluate a site's production potential before selecting it for high tunnel installation, however in many cases, soils can be amended for fertility and soil pH if all other factors are favorable for the site.

More resources on managing high tunnel soil fertility can be found in Chapter 7 of this toolkit, 'High Tunnel Soil Health'

Type and size of high tunnel

Will your high tunnel be stationary or moveable? How big of a high tunnel are you considering?

Moveable High Tunnels (Kentucky)

CCD-SP-15 (Resource 020)

- This publication discusses the benefits and considerations of moveable tunnels as well as design details and potential crop rotations.

Design

The design, dimensions, and materials of your high tunnel should also be planned before construction begins. Although there are several structural options available for high tunnels, gothic-style roofs are recommended for Kentucky because of the ability to shed snow and rain. Other design considerations include:

Budget

Knowing your budget beforehand and what you are able or willing to spend will influence many of your decisions.

Photo 4.5 There are many different sizes and kinds of tunnels. A smaller tunnel like this one might fit your budget or farm scale better than a larger one. *Source: Kathryn Pettigrew*

Dimensions

High tunnels come in many sizes. The width and length of your high tunnel will depend on your budget, your future production plans, and the site available on your farm.

Bow spacing

For Kentucky high tunnels, 4 ft bow spacing is recommended as this provides the most structural integrity and can better withstand snow loads and wind.

Structure material

Metal vs. wood. Wood will be less expensive, but metal will last longer. Wood is subject to warping and rotting. In many cases, wooden components of the high tunnel can be replaced with metal equivalents later.

Single vs. double layer plastic

If growing from spring through fall, a single layer of plastic is sufficient. If growing through the winter, a double layer should be considered. Electricity is needed to inflate the space between the two layers of plastic.

Ventilation

In addition to sidewalls and end walls, other ventilation may be added such as ridge vents, butterfly end wall vents, and interior circulation fans. Not all of these may be required but should be considered based on tunnel size and crops grown.

Roll up vs. drop down curtains

Roll up curtains are the standard option for most tunnels but if your primary crops are grown in cold weather buffer seasons, drop down curtains may be a better option to keep frost off crops.

Photo 4.6 High tunnels can be severely damaged by severe weather events. Here a tunnel has been overturned by a high wind event. Hail damage, flooding, and lightning damage are other possibilities. While some weather damage is unavoidable, others can be mitigated with proper siting and construction. *Source: Kathryn Pettigrew*

End walls, doors, and access

- For best practice management consider the width of doors based on equipment size. Choosing doors on rollers and framing materials for minimal maintenance and longevity i.e., wood vs square tubing.

Bracing

- High tunnels on sites that experience high winds and tunnel supported trellising should consider additional diagonal bracing and rafter cross ties for best practice.

Shade cloth

- Shade cloth is necessary to minimize exposure to the sun during periods of extreme heat and keeps the temperature of the tunnel cooler. Different choices are available based on the percentage of light the product blocks. Choose percentage weight based on crop grown and potential sun exposure for the specific tunnel(s) you will cover (some tunnels may already receive partial shading from trees, terrain, or nearby structures). 30% shade cloth is a versatile choice for many crops grown over the summer in Kentucky.

Other design and site selection resources

Structures and Systems for Success in High Tunnels

(Resource 021)

- This recorded presentation of Iowa State Extension and Outreach Field Specialist discussing detailed considerations for siting and constructing a high tunnel.
    - Timestamp 7:00—options for door design
    - Timestamp 13:17—temperature control and ventilation
    - Timestamp 29:38—wind management
    - Timestamp 38:57—irrigation and watering
    - Timestamp 4:25—tunnel orientation and site prep

Ventilation in Greenhouses and High Tunnels

(Resource 022)

- This article by the University of Vermont Extension discusses ventilation, circulation, and airflow in high tunnels. It highlights ventilation equipment to consider adding to your high tunnel at time of construction

A Guide to Preparing Tunnels for Extreme Weather

(Resource 023)

- In this guide, the University of Vermont Extension provides considerations to prepare tunnels for extreme weather conditions before construction
- It also discusses strategies for existing structures in snow, wind, and heat

Chapter 5 - High Tunnel Structure Maintenance

High Tunnels require regular maintenance to keep them in good condition. In addition to managing a healthy crop, growers need to routinely inspect the structure of their high tunnel. When working inside the tunnel or opening the sidewalls, make note of any damage or disrepair. Inspect the high tunnel for damage after weather events such as strong wind, hail, heavy rain, or snowstorms. The **assessment should include looking over the frame, the plastic covering, and the end and side walls. Look for holes and tears, shaky or unsteady structural components, or pieces that may have blown off**. It is important to **winterize your high tunnel** each year. This involves preparing the structure and irrigation system for freezing temperatures and snowfall.

Since the plastic covering of the tunnel is essential to season extension, it needs to be replaced when it has degraded or has excessive holes. Small patch repairs can be made to the plastic using poly repair tape which can be purchased from grower supply or hardware stores. However**, after several growing seasons or when the cover is severely damaged, consider removing the entire plastic sheet and re-covering the tunnel.** The longevity of the plastic covering depends on several factors: how well it was installed, amount and intensity of weather events (wind, hail, etc.), and sun intensity. Generally, the 6-mil polyethylene coverings last 4-5 years, but can last longer depending on installation, weather, and other factors. As the plastic ages beyond 4-5 years, light penetration in the tunnel can decrease as the plastic yellows and becomes less transparent. This impacts plant growth. When the time comes, take advantage of the removed cover to complete any other needed repairs to the frame.

Photo 5.1 Stretching new plastic. *Source: Rachel Rudolph*

While you have the plastic off you should:

- Replace any rotten hip boards or baseboards. Wooden parts will break down over time and may need to be replaced. Consider upgrading to metal components. Although more expensive than wood upfront, using metal will lead to reduced maintenance (and the costs associated with maintenance) overtime.
- Add upgrades to the basic high tunnel frame to improve your production system. Some examples of useful upgrades include adding electricity for automatic sides or modifying end walls to allow entry of larger equipment.

- Consider leaving the plastic off from November to February to allow the soil to be exposed to rainfall and other precipitation. This can assist with leaching out excess salt that may have built up in the soil.

See Chapter 7 for more information on soil salinity and management.

Check out these other high tunnel maintenance resources:

Damaged plastic

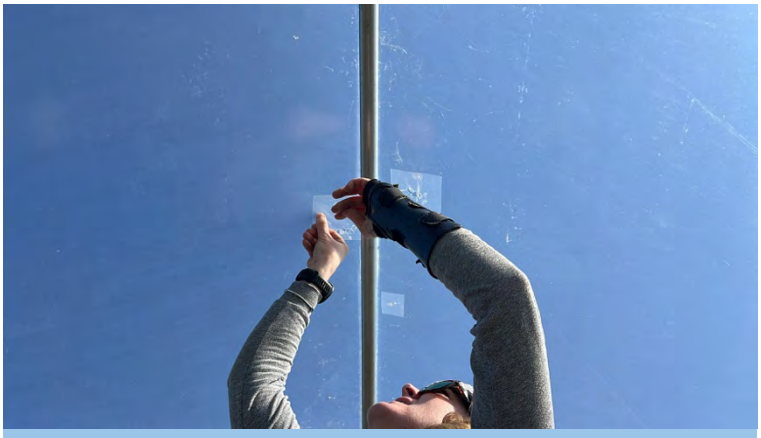

Photo 5.2 It's possible to repair small tears, holes, and other damage to the plastic, but eventually all plastic needs replacing. *Source: Kathryn Pettigrew*

Making simple patch repairs to plastic in High Tunnel Soil and Site Preparation

(Resource 024)

- This 8-minute video from the University of Kentucky gives an overview of high tunnel maintenance in preparation for spring planting. The first two minutes discuss inspecting the tunnel and making small repairs such as patching plastic.

Installing plastic

Pulling the Main Sheet of Plastic

(Resource 025)

- This is a one and a half-minute from Grow Appalachia showing how to pull the main sheet of plastic covering over a small high tunnel.

Securing Main Sheet of Plastic

(Resource 026)

- This three-minute video from Grow Appalachia demonstrates how to secure the plastic cover onto a small high tunnel.

High Tunnel: Main Cover Install

(Resource 027)

A four-minute video produced by Texas A&M demonstrating how to cover a large high tunnel. It includes the golf/tennis ball technique for pulling a large piece of plastic across the top of the tunnel to the other side.

'Covering a High Tunnel' and 'Tips for Attaching the Plastic'

(Resource 009)

1. These neighboring sections (p.44-45) from the "Construction Tips" chapter in *High Tunnels: Using Low-Cost Technology to Increase Yields, Improve Quality and Extend the Season* describe the process for covering a high tunnel and securing the plastic in a written format
2. This resource was produced by the Regional Farm and Food Project, Cornell University, USDA and distributed by the University of Vermont Center for Sustainable Agriculture.

Irrigation System Maintenance

Principles of Water Management on Small Farms

(Resource 028)

- Pages 7-8 of this resource discusses how tunnel location and farm topography may impact water in a high tunnel. This is the chapter 2 section in the publication *Water Management for Vegetable Crops on Small Farms* from Purdue University. The resource mentions managing excess water through improving runoff and drainage.

Photo 5.3 It helps to have a crew of people to help when stretching plastic. Here the installer uses special wire and channel used for securing plastic. *Source: Rachel Rudolph*

High Tunnel Winterization and Maintenance Workshop

(Resource 029)

- A video workshop from Grow Appalachia with specific information on why and how-to winterize your high tunnel including the irrigation system.
- https://youtu.be/Y1xeU4VqBBQ?si=wDC131PVH9U_9rx0

See more resources on crop irrigation in chapter 6 of this toolkit

Replacing boards and other resources

Installing the Baseboards

(Resource 029)

- A nine-minute video on installing baseboards to a high tunnel structure

Attaching the Hip Boards

(Resource 030)

- Eight-minute video from Grow Appalachia demonstrating the installation of hip boards

Photo 5.4 Many tunnels use wood in addition to metal for their structure. Wood components can wear down and get damaged. The easiest time to fix them is when you have the plastic off the tunnel for replacement. *Source: Kathryn Pettigrew*

Optimizing High Tunnel Production

(Resource 031)

- This publication from University of Vermont Extension describes ways to improve the high tunnel structure and your production practices.

A major part of maintaining your tunnel is monitoring salinity buildup in the soil. R*esources on managing high tunnel soil salinity can be found in Chapter 7 of this toolkit, 'High Tunnel Soil Health*'

Chapter 6 - An introduction to commercial high tunnel crop production in Kentucky

High tunnel crop management begins with soil sampling, selecting a suitable crop variety, planning the layout of beds, and preparing the tunnel for planting. Consider if you will direct seed or transplant the crop into the tunnel. The pre-planting process should also include setting up the irrigation system.

Irrigation, layout, and fertilization should all be customized based on recommendations for each planned crop.

After planting, using best practices for irrigation, fertility, and integrated pest management (IPM) will result in the highest possible yields for your high tunnel crop.

Photo 6.1 A tunnel growing vegetables and flowers in the same space. Some growers will grow a mix of crops while others will grow full tunnels of just one crop. *Source: Kathryn Pettigrew*

Check out the resources below for recommendations on high-tunnel crop management:

Top 5 Common Mistakes Made in a High Tunnel

(Resource 032)

- A 2-minute video from Iowa State University Extension and Outreach on common pitfalls in high tunnels management.

Soil sampling and testing

More resources on managing high tunnel soil fertility can be found in Chapter 7 of this toolkit, 'High Tunnel Soil Health'

Soil Testing: What It Is and What It Does

AGR-57 (Resource 033)

- A two-page explanation from the University of Kentucky Cooperative Extension Service on soil testing and its purpose.

Soil Testing—Commercial Horticulture Submission Form

(Resource 034)

- Kentucky Residents can submit soil samples through their county Extension office. Samples will be sent to the University of Kentucky Division of Regulatory Services for testing, and results will be returned to the grower.
- Your county Extension agent can assist with interpreting the results and go over management recommendations with you.
- Growers with more than one high tunnel should submit a separate sample for each high tunnel.

Photo 6.2 Just about any smart production plan will start with a soil test. High tunnels are no different. *Source: Kathryn Pettigrew*

Collecting Soil Samples for Testing

(Resource 035)

- University of Kentucky Cooperative Extension Service guide for taking soil samples and preparing samples for submission to a diagnostic laboratory.

High Tunnel Best Management Practices: Long Term Soil Health and Fertility

(Resource 036)

- This two-page publication discusses the four best practices of soil management for high tunnel production systems identified by Cornell Cooperative Extension.
- Recommendations include an annual soil test.

Foliar Sampling

(Resource 037)

- This is a nine -minute video from the University of Kentucky Extension Vegetable Specialist on the reasons to collect a foliar sample, how to properly collect a sample, and how it can be used along with soil sampling to determine nutrient needs in a high tunnel.

Crop planning

Selecting a crop

Crop Profiles, Center for Crop Diversification

- A collection of Crop Profile publications from the University of Kentucky Center for Crop Diversification (CCD) overviewing commercial production and market outlook for various horticultural crops in Kentucky
- Information is organized by crop-specific and system-specific resources

Community Supported Agriculture (CSA) Production Manual of the Organic Farming Unit at the University of Kentucky

HO-127 (Resource 038)

- This manual explains the production plan for the University of Kentucky Certified Organic CSA farm, standard operating procedures, and provides crop management guidelines.
- It includes a crop handbook with crop profiles to assist with planning and management.

UKCSA Share and Field Planner

(Resource 039)

- This is an Excel spreadsheet from the University of Kentucky specific for growers operating a CSA. It can help with planning for crop planting, timing, and harvesting for a 22-week CSA. This is best used on a computer where it can be downloaded and edited.

High Tunnel Tomato Production for Organic Soil-Based Systems

(Resource 040)

- This is a recorded presentation of the University of Vermont Extension Vegetable and Berry Specialist providing recommended practices for growing tomatoes in a high tunnel.

Photo 6.3 A trial evaluating lettuce in a high tunnel. Choosing the right crop for your markets is essential for high tunnel profitability. *Source: Rachel Rudolph*

- This video includes detailed information on soil and nutrient management in organic systems.

Timing of planting

High Tunnel Planting Calendars and Use Guide

(Resource 003)

- A two-page guide from the University of Kentucky Center for Crop Diversification on the principles of High Tunnel Production for season extension and instructions on how to use high-tunnel planting calendars for this purpose.

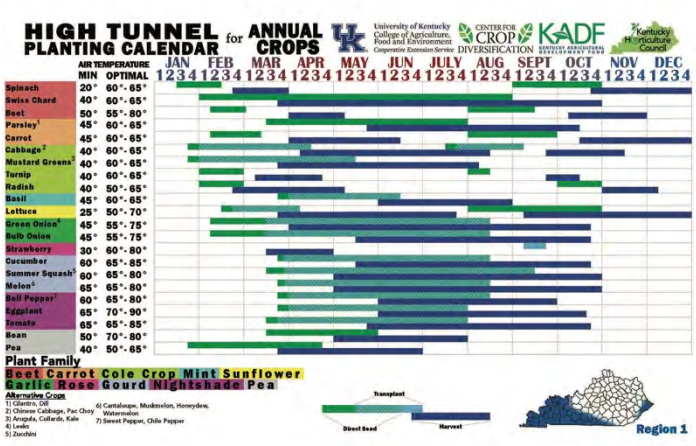

Photo 6.4 Planting date information is available in calendar form. *Source: UK Center for Crop Diversification, ccd.uky.edu*

High Tunnel Planting Calendar (Region 1—Western Kentucky)

(Resource 004)

- A planting calendar for high tunnels in Western and far Eastern Kentucky

High Tunnel Planting Calendar (Region 2—Central Kentucky)

(Resource 005)

- A planting Calendar for high tunnels in Central and Eastern KY

High Tunnel Planting Calendar (Region 3—Eastern Kentucky)

(Resource 006)

  - A planting calendar for high tunnels in Eastern Kentucky

Equipment Considerations for Vegetable Production

(Resource 041)

- During this recorded webinar, the University of Kentucky Extension Vegetable Specialist walks you through useful tools and equipment for vegetable production for different crop management tasks.

- This includes considerations before purchasing equipment, characteristics of useful equipment, and shows examples of some useful equipment and tools.
- This 38-minute video has timestamps for each equipment category (soil preparation, weed management, etc.) for easy navigation and reference.

Irrigation for your crop

Basic Irrigation for Vegetable Production

(Resource 042)

- A recorded 30-minute presentation from the University of Kentucky Extension Vegetable Specialist explaining drip irrigation for a beginning commercial vegetable system with example diagrams and photographs.
- Topics covered include components of an irrigation system, water sources, managing water pressure, irrigation zones, and determining crop water needs.

Photo 6.5 Drip or trickle irrigation is a commonly used system for horticultural crops and is recommended for use in high tunnels. *Source: Kathryn Pettigrew*

Irrigation Methods and Systems

(Resource 043)

- This is a chapter excerpt from Purdue University's publication *Water Management for Vegetable Crops on Small Farms.* It discusses using low-flow overhead and drip irrigation in vegetable production on pages 14-16. Table 1 on page 7 describes the most critical periods for irrigating specific vegetable crops.

Drip Irrigation Video Series

(Resources 044)

- This is a 4-part video series from Grow Appalachia introducing drip irrigation systems for first-time installations.
- *Part 1—Drip Irrigation Introduction*

    - This video provides an overview of the reason for drip irrigation and highlights considerations and regulations to keep in mind for irrigation systems funded by NRCS grants.
- *Part 2—Drip Irrigation Filter Assembly and Installation*
- *Part 3—Drip Irrigation Header Line Installation*
- *Part 4—Drip Irrigation Drip Tape Installation*

Go with the Flow: Simple Calculations for Small Drip Irrigation Systems

HO-122 (Resource 045)

- A 5-page extension resource from the University of Kentucky introducing the calculations and concepts used to create a small drip irrigation system.

Rainwater catchment

Off the Grid: Ultra-low Pressure Drip Irrigation and Rainwater Catchment

HO-120 (Resource 046)

- This is an 11-page publication discussing using ultra-low pressure and catching rainwater for irrigation systems.
- Includes many helpful images of components and example irrigation set-ups.
- *Rainfed Drip Irrigation* is a 24-minute video that complements the Off the Grid written resource for growers who are more visual learners:

Rainwater Catchment from a High Tunnel for Irrigation Use

(Resource 047)

- This 7-page guide with diagrams on installing a rainwater catchment system and integrating it with a drip irrigation system was published by Iowa State University Extension and Outreach.
- Information on drip irrigation systems can be found on page 6.
- Includes recommendations for summer and winter maintenance of the catchment system.

Rain Barrels Part IV: Testing and Applying Harvested Water to Irrigate a Vegetable Garden Use

(Resource 048)

- Rainwater catchment, especially off high tunnels, can have high levels of salmonella from bird droppings. This is a danger to food safety. Water can be preventatively treated to avoid contamination of crops.

- This 4-page fact sheet from Rutgers University provides guidance on how to treat rainwater.

Design of Rainwater Harvesting Systems in Oklahoma Use

(Resource 049)

- This resource from Oklahoma State University discusses the use of “first flush diverters" which can help lessen the concentrations of contaminants from rainwater catchment after a storm.

Layout, bed formation, and crop spacing

‘Interior Tunnel Layout’ from High Tunnels: Using Low-Cost Technology to Increase Yields, Improve Quality, and Extend the Season

(Resource 009)

- This manual by the University of Vermont Center for Sustainable Agriculture was written for high tunnel growers in the Northeastern USA. The information on spacing can be applied to a Kentucky high tunnel.
- See pages 57-58 of this manual for suggestions on planning the layout of your beds to maximize your growing space and accessibility.

Indiana High Tunnel Handbook

(Resource 050)

- This 36-page publication from Purdue University gives an overview of High Tunnel Production in Indiana. Much of the information can be applied to the Kentucky high tunnel system. Keep in mind the differences in climate between Kentucky and Northern Indiana that will affect planting dates.
- Pages 23 and 24 discuss the arrangement and spacing of rows in a high tunnel system.

Planting

Steps for Successful Transplanting

(Resource 051)

- A 7-minute video from University of Kentucky Extension Vegetable Specialist on how to tell if seedlings are ready to transplant and how to transplant into beds for optimum plant health.

Photo 6.6 A crew transplants lettuces into the tunnel. Transplanting is common with high tunnel crops to give them a head start for early and late plantings. *Source: Kim Leonberger*

Setting Your Transplants Up for Success

(Resource 052)

- An article by Purdue University highlighting 10 best practices for transplanting vegetable crops.

Crop management

Vegetable Production Guide for Commercial Growers

ID-36 (Resource 053)

- This is a comprehensive guidebook for growing vegetables on a commercial scale in Kentucky. Although not specifically geared towards high tunnel production, much of the information is still relevant.
- Crop-specific recommendations including suggested cultivars are organized by crop in alphabetical order.
- This resource also includes information on crop-specific fertility, insect, weed, and disease management for each crop.

High Tunnel Tomato Production

(Resource 054)

- A 50-minute webinar-style video breaking down high-tunnel tomato production in Kentucky.
- Includes:
    - Managing soil fertility

- Suggested cultivars
- Production recommendations and tips
- Post-harvest considerations

Trellising Techniques for High Tunnel Tomatoes

(Resource 055)

- A 3.5-minute video from Grow Appalachia on how to trellis tomatoes from lines suspended from the high tunnel structure.

Florida Weave

(Resource 056)

A 4.5-minute video from the University of Kentucky Extension Vegetable Specialist demonstrating how to use the Florida weave method to trellis tomato plants.

Photo 6.7 Trellising is an important part of growing tomato plants. *Source: Kathryn Pettigrew*

Crop Rotation

Crop rotation is part of Integrated Pest Management (IPM) See IPM Chapter 8 for more.

Crop Rotation Overview

(Resource 057)

- A recorded presentation by the University of Kentucky Extension Vegetable Specialist on crop rotation in high tunnels. This includes examples of rotation plans and options.

Introduction to High Tunnel Crop Rotation to Extend the Production Season

(Resource 058)

- This is a 5-minute video of the University of Kentucky Extension Vegetable Specialist introducing research on rotating high tunnel tomatoes with cut flowers.

High Tunnel Crop Rotation

(Resource 059)

- This resource is a one-hour webinar on how to practice crop rotation in high tunnels featuring the University of Tennessee Extension Vegetable Specialist.

High Tunnel Climate Management

Season Extension: Introduction and Basic Principles

(Resource 060)

- An article from North Carolina Cooperative Extension overviewing reasons and ways to extend your growing season.
- It includes a useful reference of damaging temperature thresholds for common vegetable crops.

Photo 6.8 In the heat of summer shade cloth can help keep temperatures lower when ventilation just isn't enough. *Source: Kathryn Pettigrew*

How to Manage Temperatures in a High Tunnel

(Resource 093)

- This 6-minute video from Iowa State University Extension and Outreach shows some options for managing temperature extremes in a high tunnel.

Preparing for Spring with a High Tunnel

(Resource 094)

- This 28-minute video presented by the University of Kentucky Extension Vegetable Specialist discusses the principles of season extension and various methods and tools that can be utilized in the early spring months.
- https://youtu.be/MwhXXiCFl4w

High and Low Tunnel Options for Season Extension

(Resource 095)

- A 7-minute video discussing the benefits of season extension for Kentucky growers and the use of high tunnel technology for this purpose.

Assessing Climate in a High Tunnel for Disease Management

(Resource 096)

- University of Kentucky Extension Plant Pathologist discusses the impact of high tunnel climate on disease management.

Kentucky Mesonet

- As part of the Kentucky Climate Center, weather stations across the state capture climate data. County-specific summaries, tables, graphs, and maps of the recorded measurements are available on this website. This is a great resource for county-specific weather information such as winds, temperature, and relative humidity.

Photo 6.9 Adding frost blankets inside the tunnel can provide extra cold protection. *Source: Rachel Rudolph*

Chapter 7 - Maintaining High Tunnel Soil Health

Management of soils in high tunnels is different from soil management in the open field. The higher planting density, more intense crop rotations, and lack of natural rainfall alter high tunnel soil properties over time. Additionally, as soils spend more time under the cover of the high tunnel and become different from the open field soils, management can get complex. Soil nutrient imbalances, deficiencies, and soilborne diseases often develop. This chapter is designed to provide resources to help new high tunnel growers understand the unique soil environment in high tunnels and learn management options to maintain soil health and crop productivity. There are also resources to help growers anticipate common soil-related management problems and learn basic tools to adapt to new and developing issues.

Check out the resources below for some important areas of high tunnel soil management.

What is soil health?

This site, hosted by Sustainable Agriculture Research and Education (SARE), is a good introduction to the topic of soil health and its relationship with your production system. It has an interactive diagram and links to several other resources.

https://www.sare.org/resources/what-is-soil-health/

Soil sampling and testing

Soil tests provide a lot of information about the soil fertility levels needed to manage crops this season and also give you information on trends in factors that can influence your high tunnel soil health in the long term. There are many types of soil tests; routine or standard soil tests are inexpensive tests to give you baseline information needed for crop nutrient management. Additional tests can be requested, such as soil organic matter and soluble salts (also known as soil salinity), which are helpful indicators of

Photo 7.1 Just like in the field, soil health is at the heart of high tunnel production. *Source: Kathryn Pettigrew*

high tunnel soil health and crop stress potential.

It is recommended to test soil before growing the crop in your rotation that has the greatest nutrient demand (the 'heaviest feeder'). For many growers, this will be a warm season crop such as tomatoes. Soil testing early enough to have time to act on your soil test results is important. Ideally, this would be in the fall prior to the next spring but should be at least eight weeks before planting.

See more resources on soil sampling and testing in Chapter 6 Growing Your First High Tunnel Crop

Soil Salinity

Many plant nutrients count as soluble salts in the soil. Exclusion of rainfall from high tunnels does not allow for excess nutrients to leach from the root zone, especially salts such as nitrates, calcium, potassium, magnesium, and sodium. This leads to high salt levels and nutrient and water imbalances.

Crops have varying degrees of salt sensitivity. Effects can include:

- reduced plant growth
- low yields
- appearance of burned leaf margins
- plant death.

Prevention is the most reliable strategy for managing soil salinity. In particular, choosing fertilizer and amendment sources with low salt levels (low salt index) is essential to help prevent salt from building up. To reduce elevated salt levels, allow for natural rainfall to percolate through the soil during the wet, cool months. Leaving high tunnel plastic off for 3-4 months during late fall and winter is a recommended option when possible. Otherwise, large volumes of irrigation water are needed to leach the salts past the root zone and keep them from traveling back up into the root zone.

Soil Salinity in High Tunnel Production
CCD-FS-24 (Resource 061)

This five-page factsheet from the University of Kentucky Center for Crop Diversification (CCD) explains soil salts and their impact on plants grown in high tunnel production.

Soil organic matter management

Soil organic matter is an important soil property that is a chemically complex mixture of the byproducts of every organism in the soil, living or dead. Maintaining soil organic matter levels is very important to maintaining long-term soil fertility, as it helps hold nutrients and water, prevents compaction, and binds soil particles together to improve soil structure.

Soils and Fertility

AGR 204, (Resource 062)

This chapter of the University of Kentucky Master Gardener Manual covers basic properties of soils, including nutrients and soil organic matter.

High Tunnel Soil Management for Season Extension

(Resource 063)

Warmer soil temperatures in high tunnels increase the rate of growth and breakdown of organic matter, releasing nutrients and depleting soil organic matter. Tillage, intensive crop rotations, and removing crop material to manage disease also increase the rate of organic matter breakdown and depletion. Cover crops are recommended as an important part of crop rotations to increase soil organic matter and improve soil structure (more below). This three-page article from ATTRA-Sustainable Agriculture discusses the high tunnel soil environment.

Long Term Soil Health and Fertility

(Resource 036)

This two-page publication by Cornell Cooperative Extension provides best management practices for high tunnel soil health and fertility in the long term.

Compost

Many growers turn to compost to **maintain or increase organic matter levels**, as a primary **source of fertilizer**, or as a surface mulch for **weed control in no-till systems**. If the compost is not properly managed to reach appropriate temperatures, composts may carry weed seeds, diseases, and pathogens from animal manures. Make sure your compost source is trusted and test soil salt levels regularly as manure and **manure-based composts can be particularly high in salts**, which necessitates

conservative application rates. Composts with animal manures may contain herbicides that are used to kill weeds in pastures. Some herbicides using aminopyralid (Milestone, Grazon, etc.) do not break down in animal digestive tracts or the composting process and may be found in commercial composts. If present, these herbicides may severely damage vegetable crops and may take a long time to leach or break down in high tunnels. *Always make sure your compost comes from a trusted source!*

If using compost, it is recommended to test it for salt, nutrient levels, and pH.

Compost should be tested each year even if the same source is used. Kentucky Residents can submit compost samples through their county Extension office. Samples will be sent to the University of Kentucky Division of Regulatory Services for testing and results will be returned to the grower. Your county Extension agent can assist with interpreting the results and go over management recommendations with you.

University of Kentucky submission form for manure-based composts: https://www.rs.uky.edu/soil/forms/AnimalWasteSubmittal.pdf

Sustainable Manure and Compost Application: Garden and Micro Farm Guidelines

(Resource 064)

This resource from Utah State University discusses the different factors associated with using animal manure as a fertility source, including nutrient and salinity content, application rate, and proper composting.

Photo 7.2 (left) Millet cover crop in a high tunnel in summer might be a good choice for a grower mainly using their tunnel for early and late season extension. ***Photo 7.3 (right)*** Growing a cover crop is great, but you need to be able to terminated it too. Here a flail mower attachment is used on a walk behind tractor. *Source: Rachel Rudolph & Kathryn Pettigrew*

Cover crops in high tunnel crop rotations

Cover crops can be an important part of a crop rotation in high tunnels. They can help **build soil organic matter and increase soil health** and keep **nutrients cycling**. They do not bring the risks of adding additional salts or herbicide contamination that compost may. Cover crops do require planning and time in the crop rotation to allow for both growth and decomposition.

Covers Under Cover: Managing Cover Crops in High Tunnels

CCD-SP-16 (Resource 065)

- This four-page factsheet from the University of Kentucky Center for Crop Diversification (CCD) discusses considerations for cover cropping in high tunnels such as plant selection, timing, as well as potential pros and cons.

Warm Season Cover Crops for High Tunnels in the Southeast

CCD-SP-19 (Resource 066)

- Warm season cover crops can be grown with a short amount of time in between spring and fall crops in a high tunnel. Recommended species in this guide grow quickly but should be killed and tilled in while they are a manageable size. Warm season cover crops can be planted at the end of summer and killed by frost (winter killed) and incorporated in the winter in preparation for early spring planting.
- This resource from the University of Kentucky Center for Crop Diversification (CCD) describes selection, planting, and management of cover crops in high tunnels. It includes a sample of several cover crop varieties with their potential benefits and management challenges.

Cool Season Cover Crops for High Tunnels in the Southeast

CCD-CP-18 (Resour*ce 067)*

- Cool season cover crops are good choices if you do not have a market for winter vegetables. Many cover crops that do well in the field as winter cover crops do well in a high tunnel. In this factsheet, there is information about growing cool season cover crops in high tunnels provided by the University of Kentucky Center for Crop Diversification (CCD)

Understanding the effect of irrigation water on soil properties

Basic Aspects of High Tunnel Soil Fertility Management (Indiana)

(Resource 068)

Irrigation water should be tested for alkalinity (calcium carbonate content), especially well water or if water is known to be particularly 'hard'. Calcium carbonate levels under 100 parts per million are ideal. Water pH should be between 5.5 – 6.5. This two-page resource from Purdue University describes how irrigation water can influence soil pH and salt levels in soil over time.

Why Test My Irrigation Water?

(Resource 069)

Water quality can impact plant growth and production. For this reason, it may be valuable to test your water at least once per year, especially if you use a well or open source, such as a pond or river. This two-page resource discusses why testing your irrigation water may be helpful and how to collect a water sample.

Photo 7.4 Overhead irrigation systems are sometimes used in high tunnel production. *Source: Kathryn Pettigrew*

Submitting a water sample for testing

The University of Kentucky offers irrigation water testing. Kentucky residents should submit their samples through their county Extension office.

Understanding and Managing Water Alkalinity

(Resource 070)

Once the results of the irrigation water are returned, your county agent should review them with you. This two-page resource will help with understanding the different factors influencing water quality.

Irrigation Water Quality and Mulches and Water Management

(Resource 043)

These are chapters 5 and 6 in Water Management for Vegetable Crops on Small Farm, a publication by Purdue University. Pages 17-21 provide an overview of the chemical, biological, and physical characteristics of irrigation water. Pages 21-22 discuss the

benefits of mulching related to soil moisture, various types of mulch materials, and some considerations when practicing each mulching strategy.

Water management on site

High tunnels offer the benefit of not only extending the growing season, they keep soil under the cover of the tunnel protected from rainfall when properly sited.

See Chapter 4 Site Selection and Construction This chapter offers important considerations for soil drainage when siting your tunnel.

See Chapter 6 Growing Your First High Tunnel Crop. Chapter 6 Includes resources on setting up high tunnel irrigation systems, rainwater catchment, and management water in high tunnels

Chapter 8 - Integrated Pest Management in High Tunnels

Photo 8.1 Diseased high tunnel tomato leaf. Tomatoes can be susceptible to disease in fields and high tunnels. High tunnels bring about unique challenges.. *Source: Nicole Gauthier*

Although the first year of growing in a high tunnel may feel easier than growing in the open field, it is a common misconception that high tunnel production has fewer issues. There are not fewer pests or diseases in high tunnels compared to the open field, but there may be *different* pests and diseases compared to crops grown in the field. Pest management may also be different compared to the field. Growing a profitable crop requires having a plan in place for pest and disease management to prevent, identify, and respond to problems in your high tunnel.

Integrated pest management (IPM) is a phrase that describes a well-rounded approach to dealing with all types of crop pests, which include insects, diseases, weeds, and even animals. Prevention is an important component of IPM. When issues arise, management of pests should be a combination of approaches rather than relying on only one method. Your approach to management in the current season impacts the next growing season. A successful high tunnel grower will create a plan to not only address the present problem but also develop a long-term IPM plan that will help prevent and address future issues.

Scouting in a High Tunnel

An IPM Scouting Guide for Common Problems of High Tunnel and Greenhouse Vegetable Crops in Kentucky

ID-235 (Resource 071)

This guide covers common diseases, pests, weeds, and abiotic (meaning not caused by an organism) challenges encountered in Kentucky high tunnels with images to assist with identification of issues.

- The guide can be accessed digitally, or a printed copy may be available at your county Cooperative Extension office.

- The mobile friendly web page, Veggie Scout, hosted by the University of Kentucky Department of Plant Pathology, can assist with identifying what problem you have in your high tunnel:
- https://veggiescout.ca.uky.edu/high-tunnel-greenhouse-vegetable-crops-scouting-guide

MyIPM APP for Vegetables

(Resource 072)

This application was developed by Extension Specialists across the United States.

It is available as a free download on smartphones and smart devices to assist with in-field scouting of diseases and pests. The app includes training modules with management recommendations for a specific disease or pest. https://myipm.app/vegetables/

- The How-To Guide walks you through downloading the app onto your device and navigating the resource. MyIPM How-To Guide PDF: https://myipm.app/wp-content/uploads/2024/01/MyIPM-for-Vegetables_final-SECURED.pdf

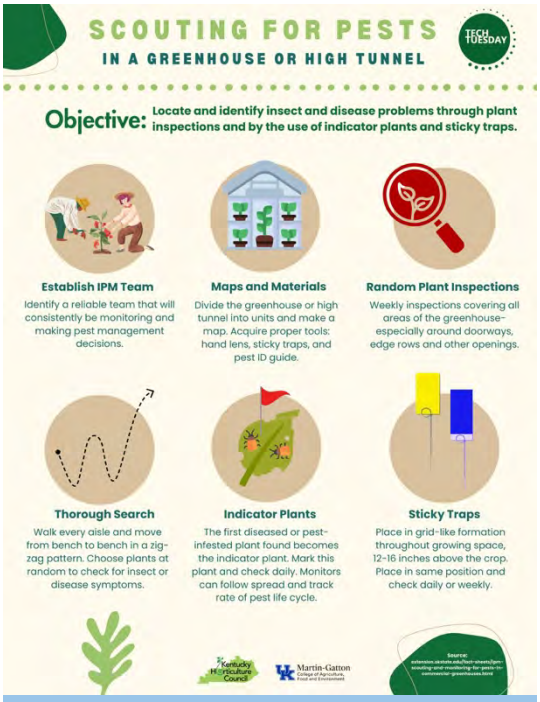

Photo 8.2 IPM Scouting guides like this one are helpful resources from trusted extension sources. *Source: Dani Zwishenberger, Kentucky Horticulture Council*

Abiotic and Physiological Disorders of Tomato

(Resource 073)

These are issues that are not caused by plant pathogens, but by too much or not enough of certain nutrients or by environmental factors such as high air temperatures or humidity.

In this 36-minute video the University of Kentucky Extension Vegetable Specialist discusses how abiotic disorders differ from diseases, what the different abiotic disorders are, and how to prevent them.

Crop Rotation

***Crop rotation is a crucial preventive tactic that can help foster an effective overall IPM approach*. Rotating crops can break the cycle of host plants for insect pests and soilborne pathogens. See Chapter 6 for more information on crop rotation resources.**

Weed Management

Weed Management Options in High Tunnels

(Resource 074)

- This 30-minute video from University of Kentucky Horticulture Specialists goes through weed management options for high tunnel production.

Insect Pest Management

Controlling Pests on High Tunnel Tomatoes

(Resource 075)

- This is a 34-minute video from the University of Kentucky Extension Entomologist summarizing a pest management program for high tunnel tomato production.

Photo 8.3 The yellow cards in these pictures are sticky insect monitoring traps that growers can use to keep an eye out for insect pests. Monitoring is a key part of IPM. *Source: Rachel Rudolph*

High Tunnel Insects

(Resource 076)

- In this seven-minute video, the University of Kentucky Extension Entomologist explains active and passive monitoring for pests in your high tunnel.

Sustainable Pest Management in Greenhouses and High Tunnels

(Resource 077)

- This is a 10-page fact sheet from Sustainable Agriculture Research & Education (SARE) that provides guidance and recommendations for using natural pests as a form of control for common high tunnel insect pests, a practice called biocontrol.

Biological Control of Arthropod Pests in High Tunnels and Greenhouses

Entfact-327 (Resource 078)

- This two-page guide from University of Kentucky Entomologists focuses on how to manage key arthropod pests in high tunnel production systems.

Biological Products for Insect Control in Greenhouses

ID-36 (Resource 053)

- Page 10 in the Vegetable Production Guide for Commercial Growers, ID-36, a comprehensive crop management guide by the University of Kentucky, provides a list of beneficial insects that can be released in high tunnels to assist with reducing pest populations.

See Chapter 6—Growing Your First High Tunnel Crop for a full description of this production guide resource.

Pesticide Calculations for Small Acreages

(Resource 079)

- This resource explains and provides examples of calculating pesticide quantities and rates for small acreages which apply to high tunnels.

Plant Disease Management

Beginner Disease Management for Vegetable Production

(Resource 080)

This resource is a recorded 40-minute presentation by University of Kentucky Plant Pathologist about vegetable disease basics.

Disease Management Roadmap for Small Acreage Growers

PPFS-GEN-25-IG (Resource 081)

- This infographic walks you through the key steps to disease management in small scale operations. It could be printed and posted for farm workers to reference.

Managing Greenhouse & High Tunnel Environments to Reduce Plant Diseases

PPFS-GH-01 (Resource 082)

- This is a guide from University of Kentucky Plant Pathology on the best practices for sanitation and management of climate, water, and soil in a high tunnel to minimize disease challenges.

Disease Management through Sanitation in a High Tunnel

(Resource 083)

- This three and a half-minute video from the University of Kentucky Plant Pathologist discusses the importance of sanitation in a high tunnel as part of disease prevention and management.

Photo 8.4 The disease Sclerotinia in a high tunnel lettuce crop. *Source: Nicole Gauthier*

Cleaning & Disinfecting Hand Tools & Planting Supplies

PPFS-GEN-17 (Resource 084)

- This resource is a four-page fact sheet from University of Kentucky Plant Pathology discussing both the importance of using clean equipment and ways to sanitize tools used on the farm.

Management of Common High Tunnel Tomato Diseases

(Resource 085)

- This is an 18-minute presentation by University of Kentucky Plant Pathologist, highlighting common disease problems encountered by high-tunnel tomato growers in Kentucky and how to manage them.

Root-knot Nematode in Vegetable Cropping Systems

(Resource 086)

Root-knot nematodes are microscopic plant-parasites that reside in the soil and cause decreased plant vigor and yield.

This resource explains plant symptoms, identification and diagnosis, and management.

Commercial Spray Schedule for High Tunnel Production of Tomatoes

PPFS-VG-31 (Resource 087)

- This resource from University of Kentucky Plant Pathology covers disease management for conventionally and organically grown high tunnel tomatoes.

- It includes an example spray schedule to limit the impact of tomato diseases to crop yield.

Commercial Spray Schedule for High Tunnel Production of Cucumbers

PPFS-VG-33 (Resource 088)

- This three-page fact sheet from the University of Kentucky contains a timeline of when common diseases of cucumber crops occur in Kentucky high tunnels.
- It also has recommended management strategies to combat these pathogens including a spray schedule based on plant growth stage.

https://plantpathology.ca.uky.edu/files/ppfs-vg-31.pdf

Photo 8.5 A trial evaluating soil solarization at the UK Horticulture Research farm. *Source: Kathryn Pettigrew*

Soil solarization

Soil solarization uses thin, clear plastic to trap solar energy and heat soil to temperatures that can be detrimental to weeds and plant pathogens. Because temperatures can be so much higher in high tunnels, soil solarization may be even more effective in high tunnels compared to the open field.

Benefits of Soil Solarization

(Resource 089)

This five-minute video discusses the potential benefits of soil solarization, including management of weeds, diseases, and insect pests.

How to Solarize Soil

(Resource 090)

This 10-minute video from the University of Kentucky Extension Vegetable Specialist is a step-by-step guide on how to effectively solarize soil, how long to solarize, and the tools you will need.

Additional Benefits of Solarization for Weed & Insect Management

(Resource 091)

This is a recorded five-minute conversation between the University of Kentucky Extension Entomologist and Vegetable Specialist on the potential of soil solarization for weed and pest management.

See Chapter 7 Soil Health for more information on managing high tunnel soils to support crop production

Wildlife Pests

Management of Wildlife and Domestic Animals on Your Farm

ID-243 (Resource 092)

- This three-page extension publication from the University of Kentucky includes Good Agricultural Practices (GAPs) for managing both domestic animals and wildlife around food production. It also includes recommendations on fencing, population control, and best practices.

Photo 8.6 This bird netting installed over side wall openings can help keep out flying wildlife and deer that might impact your crop. *Source: Kathryn Pettigrew*

UK COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF KENTUCKY — COLLEGE OF AGRICULTURE

Season Extension Tools & Techniques

Introduction

Season extension techniques can be as simple as selecting early maturing varieties; or they can be a more complex combination of multiple methods. Regardless, the objective is to extend the growing season by producing earlier crops in the spring and/or push production later into the fall and early winter.

Marketing and Market Outlook

Growers able to provide the earliest locally grown fruits and vegetables frequently capture premium prices. The same can be said for those who harvest crops well into fall and winter. A longer production season may place Kentucky growers in a better position to compete with producers to the south. Some season extension techniques can also result in higher yields and improved product quality. Extending the season has the potential of spreading out cash-flo , increasing overall farm profits, and gaining new customers

Marketing avenues include roadside stands, farmers markets, U-pick, restaurants, locally owned grocers, community supported agriculture (CSA) subscriptions, produce auctions, and wholesale markets. Growers primarily selling their produce via farmers markets may find they have to locate alternative markets for products available outside the regular season. However, some farmers markets in the state operate year round by using indoor facilities during the winter.

Specific Tools and Techniques

Planting site

The location of the growing site can have an impact on the length of the growing season available for production. Selecting a site with a southern exposure, especially a south-facing slope, can help increase the earliness of certain crops. Avoid the top of a hill, where wind exposure can be a problem, as well as the bottom of a slope where cool air will settle.

Factors that affect soil warming, such as soil type and soil color, can impact earliness, as well. Darker soils will warm up more quickly in the spring; the addition of organic matter can help to darken light-colored soils. Loam and clay soils absorb and hold the heat better than sandy soils. Soil warming is also improved in raised beds and with the use of dark mulches.

Transplants

The use of transplants is another way of getting an earlier start to the season. Harvests of transplanted crops tend to be as much as 3 to 4 weeks ahead of direct-seeded fields. In addition, transplants

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are generally better able to compete with weeds than young seedlings are.

Windbreaks

Various windbreaks can be used to protect sensitive crops from cooling winds. Brush piles, fences, fence rows, shrubs, stone walls, and snow fences can effectively block winds. Some windbreaks can perform double duty. For example, certain types of willows can serve as a windbreak while also providing woody cut material for the floral industry. Likewise, brambles can provide wind protection with the bonus of a crop of blackberries/raspberries. Perennial grass strips or small grain cover crops can act as windbreaks in the spring. Commercial windbreak materials are also available.

Windbreaks should be placed perpendicular to the prevailing winds. The goal is to provide wind protection without obstructing air circulation or forming frost pockets.

Shade

Natural or artificial shade can be used to modify temperatures during the heat of summer. This can make it possible to produce heat-sensitive crops, such as lettuce and spinach, further into the growing season.

Irrigation

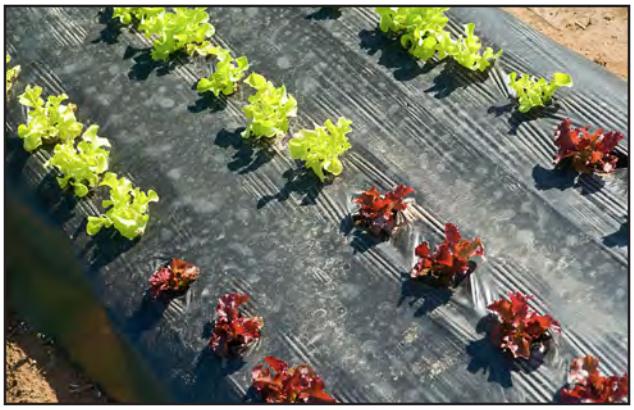
Irrigation systems, especially overhead sprinklers, may provide some protection against frost in early spring or fall.

Cultivar selection

Selecting early-maturing cultivars may result in harvests of a week or two earlier than standard varieties. Additionally, selecting cold-tolerant varieties for spring plantings and heat-tolerant ones for summer can help get the most out of the growing season. To get a range of harvest dates, use varieties with different "days to maturity" and/or stagger the planting dates.

Mulches

Plasticulture has become a widespread practice with many benefits, one of which is increased soil warming in the spring. Crops grown with black plastic mulch can be as much as 7 to 21 days earlier than those grown on bare ground. Plastic mulches are often used in combination with other season extension techniques, such as raised beds, row covers, low tunnels, and high tunnels. Irrigation is necessary when using plastic mulch.



Black is the most commonly used plastic mulch color; however, the effect of various other colors has been investigated. Clear plastic has been found to be the most effective in raising soil temperatures. Unfortunately, weeds grow under clear plastic, negating the weed control benefit generally associated with mulches. White plastic has been found to be effective in reducing soil temperatures, making it possible for cool-season crops to be planted when soils would otherwise be too warm for establishment. However, depending on its opacity, white mulch may also allow light penetration and weed growth. White-on-black mulch will still provide cooling while preventing most weed germination. Red mulch performs much as black does, but research indicates that it enhances the yields of certain crops, such as tomatoes. New innovations in plastic mulch are continually being investigated.

Black plastic mulch has its disadvantages. Some plants can overheat as the season progresses; even leaves in contact with the plastic can be damaged. Another drawback of plastic mulches in general

is the difficulty of removal and disposal at the end of the season.

Organic mulches, as well as various paper mulches, can provide some of the benefits of plastic mulches. The fact that these mulches are also biodegradable eliminates the removal and disposal problem inherent with plastic. However, organic mulches may have a cooling effect on the soil and result in the delayed emergence of spring crops.

Floating row covers

Floating row covers consist of large sheets of lightweight fabric placed over single or multiple rows of a crop to provide some protection against frost. The covering may be made of clear polyethylene, spunbonded polyester, or spunbonded polypropylene. The fabric comes in different weights; the heavier the material, the greater the frost protection. Row covers can be used in fall, as well as early spring, to extend the season. When used to protect spring crops, covers are removed before the plants mature, while fall frost protection necessitates leaving the covers on mature plants.

The fabric, which basically "floats" on the crop as it grows, allows rain, air, and sun to penetrate. In addition to frost protection, row covers may provide a barrier to some insect pests and wildlife. Covers need to be removed from fruiting plants during bloom to facilitate insect and/or wind pollination. Row covers can also cause abrasions of some crops as the fabric rubs against the foliage and tender growing tips.

Low tunnels

Low tunnels are wire or PVC hoops covered with clear plastic or fabric row covers. The covers are generally in place for only three or four weeks and then removed. Besides providing an excellent means of extending the growing season, low tunnels also offer wind protection.

Low tunnels with a plastic covering do not permit rain to penetrate so they are often used in conjunction with black plastic mulch and drip irrigation. Low tunnels also trap heat so that daytime temperatures can rise to dangerous levels within the tunnel, making ventilation essential. Various modifications to the original low tunnel design and covering have been made to allow for increased air circulation. These include pre-cut slits in the covering material, a "seam" running down the center top of the tunnel that can be opened on hot days, raising one side of the tunnel covering, and the double-hoop system that allows for raising and lowering both sides.

High tunnels

The field greenhouse of the past is now generally called a "high tunnel" or "hoophouse." A high tunnel is a hooped frame of walk-in height covered with plastic. Tunnels may have a rounded Quonset shape or they may have the peaked roof of a Gothic style high tunnel; they may be a single stand-alone house or form multi-bay tunnels. High tunnels can be erected as moveable structures that are relocated to a new site each season, or they may be placed in a more permanent location. If the tunnel is to remain in one location, it is important to remember that salts can build up in the soil from fertilizer applications. Plan on removing the plastic cover

as needed to allow natural precipitation to flush the salts from the soil.

The frames, which can be constructed of metal pipe, wood, or PVC pipe, are covered with one or two layers of greenhouse-grade polyethylene; those covered with two layers of plastic have an air layer in between, thus offering better insulation and, consequently, more cold protection.

Tunnels are generally ventilated by manually rolling up the sides each morning and rolling them back down in the evening. However, a system that is becoming more common has drop-down side walls. Some designs feature removable or hinged end walls so a small tractor or tiller can be driven in. Covering the entire soil surface under the tunnel with plastic mulch makes tilling unnecessary. While high tunnels do not have a permanent heating system, a portable heater can be used when unexpected drops in temperature occur. When vented properly, serious foliar and fruit diseases are often fewer since plant surfaces remain dry while in the protective environment of the high tunnel.

A wide variety of crops can be grown in irrigated ground beds within the tunnel. These include vegetables, small fruits, and flowers. In addition to extending the season earlier into spring and later into fall, high tunnels can be also be used for the winter production of various cool-season crops, such as greens and herbs.

Yields have been reported to be as much as double the amount that could be produced in the field without the tunnel. A combination of an earlier planting date, along with the more rapid ripening that occurs within the tunnel, can result in mature tomatoes as much as one month earlier than field tomatoes

Economic Considerations

A number of season extension techniques are relatively inexpensive and require little capital investment. Even the more costly techniques, such as row covers and tunnel structures, can be relatively economical.

The approximate cost of a floating cover is less than a penny per square foot, excluding labor costs. The approximate construction cost of a low tunnel may range from $0.25 to $0.50 per square foot. Excluding labor, material and equipment costs for high tunnel construction may range from about $1.00 to $2.50 per square foot; the use of more expensive irrigation and heating technologies are reflected in higher costs per square foot. Plastic mulch and irrigation costs are approximately $0.20 per square foot.

Because of their simple design, tunnel structures are not difficult to construct and manage. However, since they are not automated in any way, high tunnels will require daily attention and labor to ensure proper ventilation. This can also be the case with low tunnels. Row covers and tunnels could also require monitoring during heavy storms. The additional management/ labor requirements of some season extension techniques, not to mention the increased demands of a longer growing season, can result in higher production costs. However, growers able to obtain price premiums for their early and/or late season crops may be able to at least recoup these costs, possibly even receiving higher profits.

Growers should carefully weigh the costs of season extension techniques against the potential profits. Costs may be spread across multiple crops during different times of the year. For example, overhead irrigation equipment used for fruit frost protection could be used for other crops during

the summer. Evaluating the economic effects of season extension upon the whole farm production and marketing plans will help gauge the total costs and benefits affiliated with different levels of investment in materials and equipment.

Selected Resources

- Extend Your Vegetable Season (University of Kentucky) *5.71 MB file*
http://www.uky.edu/Ag/Horticulture/seasonextension.pdf
- Plastic Tunnels Provide Expanded Production Opportunities (University of Kentucky, 2004)
http://www.ca.uky.edu/AGC/NEWS/2004/Jan/tunnel.htm
- Bumper Crops Early And Late: Season Extension Using Plasticulture (Kerr Center for Sustainable Agriculture, no year) *3.21 MB file*
http://www.kerrcenter.com/futurefarms_08/presentations/upson.pdf
- Center for Plasticulture (Pennsylvania State University)
http://plasticulture.cas.psu.edu
- Extending the Production Season for Vegetables and Small Fruit (University of Maryland, 1999)
http://extension.umd.edu/publications/PDFs/FS760.pdf
- High Tunnels (Kansas State Research and Extension, University of Missouri Extension and University of Nebraska Cooperative Extension)
http://www.hightunnels.org
- Marketing Strategies for Farmers and Ranchers: Season Extension (SARE, 2004)
http://www.southernsare.org/Educational-Resources/Bulletins/National-SARE-Bulletins/Marketing-Strategies-for-Farmers-and-Ranchers/Text-Version/Season-Extension
- Midwest Season Extension (Midwest Organic and Sustainable Education Service)
http://midwestseasonextension.org/default.htm
- Season Extenders (Virginia Tech, 2009)
http://pubs.ext.vt.edu/426/426-381/426-381.html
- Season Extension Techniques for Market Gardeners (ATTRA, 2005)
https://attra.ncat.org/attra-pub/summaries/summary.php?pub=366
- Sustainable Season Extension: Considerations for Design (ATTRA, 2011)
https://attra.ncat.org/attra-pub/summaries/summary.php?pub=370
- Use of Different Colored Mulches for Yield and Earliness (University of Connecticut, 1999)
http://www.hort.uconn.edu/ipm/veg/htms/colrmlch.htm
- Use of Plastic Mulch and Row Covers in Vegetable Production, F-6034 (Oklahoma State University, 2007)
http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-1099/F-6034%20web.pdf

Reviewed by Bob Anderson, Extension Specialist (Issued 2007)
Reviewed by Shawn Wright, Extension Specialist (Revised 2011)
Photos by Matt Barton (transplants, pg 1; plastic mulch, pg. 2), Steve Patton (shaded tunnel, pg.2), Mark Williams (row covers, pg. 3), and Tim Coolong (low tunnel, pg. 3), University of Kentucky; and USDA-NRCS (high tunnel, pg. 4)
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University of Kentucky
College of Agriculture, Food and Environment
Cooperative Extension Service

Center for Crop Diversification System Profile
CCD-SP-2

High Tunnel Overview

Cheryl Kaiser[1] and Matt Ernst[2]

Introduction

High tunnels, also known as hoop houses, are relatively simple polyethylene-covered greenhouse-like structures that are passively heated and cooled. Crops grown in high tunnels are usually grown directly in the soil. High tunnels can be used to extend the production season and marketing window of a wide variety of crops. They have been used in Kentucky to produce early and late-season vegetables, cut flowers, brambles, and strawberries. High tunnels can also make it possible to produce leafy greens and herbs during the winter. Shaded, well-vented high tunnels can be used to grow some cool-season crops later into early summer.

In addition to the potential for season extension and off-season production, high tunnels afford a number of other advantages. They provide protection from unfavorable weather conditions, including wind, hail, frost, and excessive rainfall. This can help improve the survival rate of perennial crops, as well as result in faster plant growth, higher yields, improved produce quality, fewer culls, and more marketable produce for many crops. Insect and disease problems are often less severe in a high tunnel; fewer pests can mean improved organic production potential. High tunnels also provide a sheltered environment for laborers during planting, production, and harvest operations.

Marketing and Market Outlook

High tunnels can allow producers to extend the time period over which cash flows are generated from specialty crops. Maximum returns will be realized for exceptional quality crops harvested when the traditional open field production season has not yet begun or has ended. This extended harvest season, along with higher yields of quality produce, should provide high tunnel growers with a marketing advantage. Early crops attract consumers to a farm operation and may help retain those customers throughout the season. Demand can vary greatly according to a local area, so producers should identify what other high tunnel production is nearby. Simple marketing plans can help producers identify the nuances of their local markets and adjust planning and production accordingly.

High tunnel production is more expensive than open field production due to the costs involved in constructing and maintaining the structure. For high tunnels to be economically viable, growers need to be able to recoup this investment. One way to defray this cost is to demand premium prices for these out-of-season tunnel crops, especially if high quality and steady supply are maintained. High tunnels may make it possible for some growers to produce

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[1]Cheryl Kaiser is a former Extension Associate with the Center for Crop Diversification.
[2]Matt Ernst is an independent contractor with the Center for Crop Diversification.

crops they would not otherwise be able to grow in open, unprotected field situations, thus providing additional revenue. Organic production within the tunnel is another means of adding further value to these crops and recouping the high tunnel investment.

Direct markets such as on-farm retail markets, roadside stands, farmers markets, and community supported agriculture (CSA) may provide the greatest premiums to producers of early crops. High tunnels can also be a good fit for producers selling to local restaurants, especially restaurants willing to pay premium prices for early and late season, locally grown crops. Early and late-season crops could also be marketed wholesale to grocery stores and through produce auctions.

Farmers market producers who extend their season into fall and winter, when many farmers markets are not open or have limited hours, could generate a subscription list and establish a pickup location or delivery service for those high tunnel crops. An email distribution list and/or social media are great ways to notify customers of product availability, as well as the order deadline for the week. Orders can then be received via return email or by phone.

Advantages of High Tunnel Production
- Extend the season (spring and fall)
  - Higher prices
  - Higher yields overall
  - Retain workers longer
  - Retain old customers
  - Gain new customers
  - Possibility of year-round income
- Improve quality of fruit
- Protection from severe weather
- Control amount of water applied
- High production in small space

Disadvantages of High Tunnel Production
- No break in work schedule
- Increased management required (rolling sidewalls up/down)
- Higher cost of production (gas, electricity, materials)
- Plastic disposal required

Tunnel Construction

Types of Tunnels

Tunnel design, dimensions, and construction materials all have an impact on the structure's use and performance. Before building or purchasing any tunnel, it is important to plan ahead to make sure the selected design and size will meet the grower's future (as well as immediate) needs for the life of the tunnel. Well-constructed, properly maintained tunnels can last for 20 years.

Tunnels are often categorized by the shape of their roofs. The two main types are quonset and gothic.

QUONSET tunnels have a rounded roof that generally extends from "ground to ground," giving the structure a semi-circular shape. Quonsets are among the simplest and least expensive tunnels to construct. The tunnel height along the sidewalls, however, limits the types of crops that can be grown in that space. Alternately, the hooped roof may be set on straight sidewalls to increase the vertical growing space along the outer walls. The rounded roof of the quonset tunnel does not shed snow readily, making them more likely to suffer damage from a heavy snow load. Spacing the hoops at closer intervals and/or bracing the bows with cross braces are ways to strengthen the structure. Another alternative is to remove the plastic covering during the winter, at least when significant snowfall is expected. Tunnels constructed from PVC pipe are particularly vulnerable to collapse from snow. Quonset style tunnels may be either single bay or multi-bay. The Haygrove tunnel is an example of a multi-bay, three-season tunnel that can be used to cover larger acreages.

GOTHIC style tunnels have a peaked roof and straight sidewalls. The steeper roof sheds snow and ice more readily than the rounded roof of a quonset tunnel. Additionally, condensing moisture within the tunnel tends to run down the sloping roof to the sides, rather than dripping on the plants below. The straight sides provide more usable growing space along the outer walls than the typical rounded quonset. In addition, the greater height of the gothic tunnel permits the production of taller crops. This height also helps increase air circulation, especially when vents are installed at the gable-ends. Gothic style tunnels are built only as single bay structures.

Endwalls

Endwalls can vary considerably in their design. They may be framed with wood or metal, or they may simply have an unframed plastic curtain that can be rolled up or pulled back. Framed endwalls, which add strength and stability to the high tunnel, are constructed after the tunnel itself is assembled. Fixed end-

The two main types of tunnels based on roof shape are gothic (at left and above) and quonset (below left). Although quonset style tunnels are the least expensive, gothic styles offer several advantages: 1) The straight sides offer more growing space on both sides of the tunnel and facilitate weed management; 2) the additional height allows space for taller crops and offers greater air circulation; 3) condensation runs down the angled roof to the sidewalls, preventing it from dripping on crops; and 4) the slanted roof allows snow and ice to run off the tunnel more readily than does the rounded roof of a quonset tunnel. Quonset tunnels can be set on straight sidewalls to increase the amount of growing space available. Quonset tunnels can be set up as either single bay or multibay, such as a Haygrove tunnel (below right).

Movable tunnels (at left) can be relocated to a new site each growing season to facilitate crop rotation. Tunnels can be built on skids or runners to make them easier to move.

walls may have just a single or double storm door/screen door built into one or both ends for worker access. Some framed endwalls have a large rectangular section hinged at the top so that the endwall can be opened. These may completely swing open or fold up accordion style. Others have sliding doors or removable panels. Tunnels in which a large portion of the endwall can be opened or removed not only have better ventilation, but also afford easier access for equipment. Gable end vents installed near the peak of gothic style tunnels offer additional air exchange. The choice of endwall design will depend largely on tunnel size, grower needs, construction costs, and personal preference.

Sidewalls

The most common type of sidewall rolls down from the hip board about halfway up the side. Another type of sidewall that is becoming more common is the "drop down" sidewall. These are raised up or lowered down to the bottom board. An advantage to this type is it prevents cold air from blowing directly over the plants and it also provides some protection from wildlife.

Tunnel size

There are a number of factors that should be considered when deciding on the size of the high tunnel. Obviously, the tunnel should be tall enough for workers

to walk into comfortably. The size and height of any necessary equipment and machinery should be considered when determining how tall the tunnel needs to be. The amount of maximum vertical space required for the various crops that will be grown in the tunnel is another determining factor for tunnel height. Adequate square footage should be available for planting, producing and harvesting the various crops, as well as for maneuvering small tractors or any other equipment that will be used in the tunnel. Typical tunnels are 9 to 15 feet tall, 15 to 30 feet wide, and 60 to 96 feet long.

Size will also affect the environment within the tunnel, especially heat retention and air movement. For example, while narrow tunnels are easier to ventilate than wider ones, narrow tunnels also experience more heat loss on cold nights. Long tunnels are more difficult to ventilate, especially if they are wide. Tall, wide houses typically retain heat in winter better than short, narrow tunnels.

Movable vs. Permanent

The high tunnel concept seems to suggest mobility; however, tunnels are often built in such a way that they are difficult to move without considerable effort. As a result, they often remain on the same site for a number of years before being moved to another location (semi-permanent) while others are never moved (permanent).

Typically, permanent/semi-permanent structures have in-ground posts, galvanized steel bows, and rot resistant wood baseboards. Endwalls can be constructed of steel or wood. When tunnels are not moved each year, the grower will need to implement a good crop rotation program. Tunnels that remain in the same location year after year, where either no rotation or a short rotation is practiced, can have high levels of soil pathogens and insect pests, leading to serious crop losses. Fertilizer salt build-up will become a problem unless the plastic covering is removed to allow precipitation to flush salts from the soil. Once in place, soil preparation in these tunnels each year can present a challenge. Hinged endwalls permit easier access for small equipment. When the endwalls are fixed, soil preparation will need to be accomplished by hand or with a small power tiller.

Movable tunnels may be built with PVC bows, which not only makes them lighter, but cheaper to construct. Only quonset style tunnels can be built from PVC. Tunnels built with steel bows but without in-ground posts are easier to move; however, tunnels that sit on top of the ground will be more vulnerable to wind damage unless they are well-anchored. Another way to make the tunnel more mobile is to build it on skids or runners. An important advantage to movable high tunnels is the ability to relocate them to a new site each growing season to facilitate crop rotation. The soil in movable tunnels is worked prior to erecting the structure.

University of Kentucky researchers are experimenting with a low-cost movable tunnel design that can be quickly disassembled and moved to a new site. The PVC bows are fitted over pieces of steel pipe that have been driven into the ground. Tunnels are constructed over already formed beds, making it possible to use traditional tractors and transplanters prior to constructing the tunnel.

Covering

One or two layers of greenhouse-grade polyethylene (4 to 6 mil) are used as the covering. Those covered with two sheets have an air layer in between, thus offering better insulation, and consequently, more cold protection. Two layers will require an inflation fan, which in turn requires access to electricity or installation of a solar system for power. Occasionally growers will insert Styrofoam blocks between the layers of plastic if they do not have electricity to their tunnels. While the second layer of plastic does offer greater heat retention, it also reduces light penetration into the tunnel. When using a single layer of plastic, low tunnels or floating row covers can be used within the high tunnel for additional cold protection.

The plastic film used to cover a high tunnel can be treated to reduce condensation dripping on plants. Additionally, an infrared re-radiate material (infrared blocker) added to the film reduces overnight heat loss. As the plastic ages, the amount of light transmitted through it will be reduced. The plastic covering should be replaced approximately every four to five years

When a high tunnel is used for the summer production of cool-season crops, the frame is covered with shade cloth. The shade cloth, which is used either alone or on top of the polyethylene, reduces light intensity and

air temperature within the tunnel. The combination of shade and irrigation keeps soils cooler, as well.

Trellising
Some crops grown in a high tunnel may require trellising. Unless the frame has been reinforced to support the heavy load of fruit-laden plants, trellising to the tunnel roof is not advisable. An overhead bracing system can be used to suspend lines for plant support, or a separate trellis system can be constructed inside the high tunnel if needed.

Site selection and orientation
Tunnel location and orientation, in addition to the site soil conditions, are essential to production success. Site selection is more critical when the high tunnel is built to be a permanent structure; however, it is an important consideration even when constructing semi-permanent or movable tunnels.

Select a naturally fertile, well-drained site in full sun that is near a reliable water supply for irrigation. A level surface is generally needed for the high tunnel frame. An exception is the multi-bay Haygrove tunnel, which does not require a level site. Avoid hilltops or other areas subject to high wind. Providing a windbreak can help reduce the threat of wind damage to the tunnel. On the other hand, the site should have good airflow for ventilation. Stay away from low sites that are poorly drained or likely to serve as frost pockets, as well as sites too close to wooded areas. Orienting the house perpendicular to the prevailing wind on the farm will help facilitate cross ventilation in the tunnel. However, for sites where strong winds are a concern, it is best to orient the tunnel parallel to prevailing winds. For maximum sun exposure during the fall and winter, the tunnel should be oriented in an east-west direction. When constructing multiple tunnels, make sure that they do not shade one another.

Placing the tunnel on ground that is slightly higher than the surrounding area helps prevent water from flowing into the tunnel during heavy rains. It is important to have the ground slope away from the base boards on the outside of the sidewalls. Alternately, a shallow trench along the outside perimeter can keep water from entering the tunnel, but this is typically done as a last resort after a grower discovers water is entering the high tunnel.

Tunnel Management

Temperature and ventilation
High tunnels are passively solar-heated, and nighttime low temperatures may drop to the outside temperature. Row covers used in conjunction with the high tunnel will provide additional cold and frost protection. Because row covers also block sunlight, they should not be left on for prolonged periods during the winter. Placing the row covers over hoops will help to keep tender leaves from freezing to the fabric. As an alternative, a heater can be used when unexpected drops in temperature occur. However, due to rising energy costs, the use of heaters should generally be limited to short durations. A grower who has received Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP) funds to purchase a high tunnel should check his/her state's NRCS High Tunnel System Conservation Practice Standard to make sure heaters are allowed. NRCS allows the permanent installation of heaters in Kentucky. Such additions should be included in the manufacturer's design and recommendations.

High tunnel temperatures cannot be regulated exactly because the tunnel environment is determined by the presence (or absence) of sun for heat and wind for cooling and ventiliation. Temperatures can be manipulated by adjusting the sidewalls as needed. The sidewalls can be left closed in early spring, but may need to be opened as daytime temperatures rise. However, once the warmer weather of summer arrives, the sidewalls should be left open. This is generally done manually; however, automatic systems are also available. Removing or opening the endwalls is another way to increase ventilation. During sunny days, temperatures in the tunnels can reach 30 degrees F to 40 degrees F higher than outside temperatures, necessitating that tunnels be adequately vented. Improperly ventilated tunnels will overheat quickly.

Because tunnels prevent natural rainfall from reaching plants, drip irrigation is essential. The irrigation system can also be used to provide fertilization during the season. Iowa State University has developed a system for catching, storing, and reusing rainwater run-off for irrigation in a high tunnel. Although this system is best installed at the time of high tunnel construction, it can be added to an existing tunnel. To learn more, refer to the publication in Selected Resources below.

Pollination within the tunnel

Pollination may present a challenge for some plants grown in a high tunnel. Honeybees may not effectively pollinate crops in this production system since they require UV light to navigate and often become disoriented under the plastic covering. High tunnel growers may need supplemental bumblebee hives if they do not observe sufficient natural pollinator activity within the tunnel. Reportedly, mason bees and alfalfa leaf cutter bees may be used as a supplemental source of pollination.

Pollination of tunnel-produced self-pollinating crops, such as tomatoes, is not adversely affected as long as there is good air movement through the structure. If the tunnel sidewalls need to be kept down for extended periods of time, it may be necessary to promote pollination by vibrating plants, by tapping the crop support system (i.e. stakes or cages), or by using a leaf blower.

Pest management

Diseases that plague field-grown crops are often less of a threat in high tunnels. However, because of the unique environment within tunnels, growers may encounter different diseases than in the field. Because the tunnel excludes rainfall, the foliage tends to stay dry, resulting in fewer foliar disease problems due to those pathogens spread by rain splash or requiring leaf-wetness for infection. In contrast, powdery mildew and rust diseases, which require high humidity for infection, but not leaf wetness, could become a problem in a tunnel environment.

Insect pests in tunnels differ as well. While the high tunnel presents a barrier to some insects, it is an ideal environment for others, particularly whiteflies and aphids. Mite infestations often become a more serious problem in a tunnel than in the open field due to the drier tunnel environment. Grasshopper feeding has been known to occur throughout the winter on crops, such as greens, since the ground within the tunnel does not freeze. Without natural predators, such as birds, to help keep insects in check, serious pest infestations may develop very quickly.

Due to the relatively high density of plants in tunnels, insects and diseases tend to spread rapidly. Frequent scouting to monitor populations is essential for keeping ahead of potential problems. Pesticides registered for open field production may not be registered for use in the enclosed space of the high tunnel. It is important to always read the label of any product in order to ensure that it is permitted to be used in a high tunnel. In Kentucky, a greenhouse and a high tunnel are considered the same regarding pesticide applications. If the label indicates that a product is not permitted in a greenhouse, it is also not permitted in a high tunnel in Kentucky.

Weed management prior to tunnel construction is important. Do not construct the tunnel on sites with high noxious perennial weed populations. Other pre-plant strategies include tillage, crop rotations designed to reduce weed pressure, and weed suppression via cover or smother crops. Once the tunnel is built, plastic or organic mulch can be used to suppress weeds within rows and along tunnel edges. Rototillers and/or hand weeding is used for managing weeds within the tunnel. It is best to have a vegetation-free strip around the outside of the tunnel as well to prevent weeds or grass from entering the tunnel from outside.

Tunnels with covers left in place throughout the winter will experience increased rodent activity when these animals discover the warm, sheltering environment that the tunnel provides. Traps can help control rodent populations in the tunnel and bait stations outside the tunnel will also help. Occasionally rabbits, raccoons, groundhogs and deer will also find their way inside a tunnel to feed on the crops when the sides or ends are left open.

Harvest

The protection offered by the tunnel means that crops can be harvested regardless of the weather. Not only are harvesters protected from the elements, but they also do not have to contend with muddy fields or wet produce.

Labor requirements

Labor requirements for establishing high tunnels vary considerably by high tunnel type and system, operator experience, and the useful life of the plastic covering. Average construction times for unheated quonset-style high tunnels of 2,000 to 2,500 square feet range from 65 to 100 hours. Labor times for erecting heated or larger tunnels can move toward 150 hours. Time needed for site preparation, and the amount of time needed for replacing shorter-lived coverings, can greatly impact labor requirements.

Economic Considerations

High tunnels are a relatively inexpensive way to extend the growing season. Excluding labor, the approximate cost of a less permanent high tunnel is $1.30 to $1.50 per square foot. More permanent structures are likely to fall in the $2.50 per square foot range, and high tunnels constructed from kits may cost even more per square foot. Site preparation and the desired level of systems investment for ventilation and heating can increase high tunnel establishment costs. Compared to a traditional production-ready greenhouse, high tunnel structures are not as difficult to construct and require less capital investment per square foot. High tunnel production, however, does represent a much greater investment than growing produce in the field.

EQIP Seasonal High Tunnel Initiative

The USDA-NRCS EQIP High Tunnel System Initiative offers financial and technical assistance to agricultural producers interested in pursuing high tunnel crop production. Refer to their website, listed under Selected Resources, for further details of the program, including eligibility requirements and application deadlines.

Selected Resources

- University of Kentucky High Tunnel Research Facility http://ukhtrf.webs.com/
- How to Build a High Tunnel (University of Kentucky, 2005) http://www.uky.edu/hort/sites/www.uky.edu.hort/files/documents/hightunnel.pd
- Costs to Build a Metal-Hoop High Tunnel (Texas A&M AgriLife Extension, 2018) http://counties.agrilife.org/collin/files/2019/03/EH_-105-Costs-to-Build-a-Metal-Hoop-High-Tunnel.pdf
- Cornell High Tunnels (Cornell University) http://blogs.cornell.edu/hightunnels/
- Design and Construction of High Tunnels in West Virginia https://www.sare.org/Learning-Center/SARE-Project-Products/Northeast-SARE-Project-Products/Design-and-Construction-of-a-High-Tunnel-in-West-Virginia
- Economics of High Tunnel Vegetable and Strawberry Production in the Central Midwest (Purdue University, 2007) 1.2 MB fil https://ag.purdue.edu/hla/fruitveg/Presentations/econ_summer_crop6.pdf
- EQIP High Tunnel System Initiative http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/programs/?&cid=stelprdb1046250
- High Tunnels (Kansas State University and University of Nebraska Extension Services) http://hightunnels.org/
- High Tunnel Production: The Basics for Success and Three Case Studies on Profitability (Universit of Maryland Extension, 2013) https://extension.umd.edu/sites/extension.umd.edu/files/_docs/FS-957%20High%20_unnel%20production.pdf
- High Tunnel Resources (Pennsylvania State University) https://extension.psu.edu/catalogsearch/result/?q=high+tunnels
- Natural Ventilation in High Tunnels (HighTunnels.org, 2012) http://hightunnels.org/natural-ventilation-in-high-tunnels/#:~:text=Natural%20Ventilation%20in%20High%20Tunnels%20Roll-up%20sides%20and,is%20required%20to%20operate%20fans%20to%20move%20air
- Portable Poly Pipe High Tunnel Hoop House Construction Plans (Noble Research Institute, Oklahoma, 2012) http://www.noble.org/ag/horticulture/poly-pipe-hh-plans/
- Rainwater Catchment from a High Tunnel for Irrigation Use (Iowa State University, 2012) https://store.extension.iastate.edu/product/Rainwater-Catchment-from-a-High-Tunnel-for-Irrigation-Use

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Reviewed by Rachel Rudolph, UK Extension Vegetable Specialist, and Shawn Wright, UK Horticulture Specialist

Photos courtesy of Christy Cassady, UK (squash in high tunnel, Page 1; gothic tunnel, upper right, Page 3); USDA-NRCS (quonset tunnel and gothic tunnel, upper left, Page 3); Mark Williams, UK (multi-bay tunnel, Page 3); David Stalion, UK Agricultural Communications (movable tunnels, Page 3) **January 2021**

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University of Kentucky
College of Agriculture, Food and Environment
Cooperative Extension Service

Center for Crop Diversification Fact Sheet
CCD-FS-9

High Tunnel Planting Calendar

By Joshua Knight[1] and Rachel Rudolph[2]

Introduction

This publication was developed to be provided with the High Tunnel Planting Calendar and not meant to be a comprehensive guide to high tunnel production. The reader should consult the Center for Crop Diversification (CCD) Publication titled High Tunnel Overview (CCD-SP-2) for a concise guide on the use and principles of high tunnel production and season extension.

Principles of High Tunnel Production/ Season Extension

Put simply, high tunnel production is a practice used to provide moderate climate control. One benefit of the climate control is the extension of the regular growing season, both in the spring and fall. Highly variable weather patterns during the spring and fall can create instability from a production and marketing standpoint. By providing protection from the elements, high tunnels provide a certain level of stability for their crop and their market. Because high tunnels provide protection from cooler weather, growers are able to start planting earlier in the spring while also harvesting later into the fall (compared to typical field production) which can also create additional income.

While some protection from cold weather patterns is expected of high tunnels as growers move into the fall and winter, there will be days of cool weather and minimal sunshine where the plants are not killed, but they are not actively growing. They are surviving, but not thriving. In planning for the extended end of a season in high tunnel production, certain crops that are ready to harvest can be kept in this stage as a form of "in-ground" storage and harvested as needed. This allows a grower to reduce dependency on cold storage infrastructure while keeping produce in a fresh state.

Using this Infographic

The numbers under each month (**1, 2, 3,** and **4**) represent weeks for each month.

The **Direct Seed** (Green), **Transplant** (Light Blue), and **Harvest bars** (Dark Blue) represent typical intervals in average years for activity of the crop or crop group in the corresponding row (Figure 1). The diagonal blue and green section means that one can **Direct Seed and Transplant** during this time.

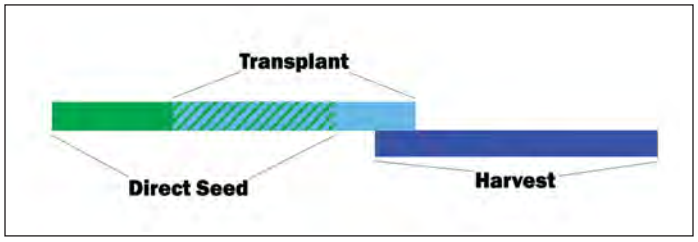

Figure 1.

These are based on conservative estimates of weather and climate patterns developed over the last few decades and should be regarded as flexible depending on air and soil temperatures each year. In using this calendar, let the current weather patterns and the predicted short term weather dictate farm activity. The High Tunnel Planting Calendar should be thought of as a fast reference to help growers plan ahead, time their different crop plantings, and/or try new crops in a high tunnel.

When approaching the time of the year indicated by the activity bars, it is important to consult the temperature col-

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www.uky.edu/CCD

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[2]Rachel Rudolph is an Assistant Extension Professor in the Department of Horticulture.

umn for the specific crop or crop group. Both columns refer to the air temperature inside the high tunnel and it should be noted: thermometers are a critical instrument in high tunnel management. **MIN** (short for **Minimum Temperature**) is the point at which tissue damage and plant death can occur. **OPTIMAL** refers to the **Optimal Temperature Range**, or the range where tissue growth occurs and plant health thrives. Hours and entire days spent inside this range are necessary for the plant to continue developing, maturing, and reaching harvest.

The crops listed along the left column have a background color that corresponds to their **plant** or **botanical family**. In general, growers can reduce the risk of disease pressure by not planting crops from the same family in the same soil in consecutive years.

Some crops listed in the left column have a number notation (**1-7**), which refers to the **Alternative Crops** section in the bottom left corner. For example, **parsley** has a similar temperature and timing interval to **cilantro** and **dill**.

If you are a grower and you are not in the **Region** noted on your planting calendar, you can estimate the timing interval for another region by adding or subtracting days (Figure 2).

Generally speaking, growers in **Region** 1 can plant/harvest approximately 10-14 days earlier than **Region 2** and 21 days earlier than **Region 3** in spring. Conversely, growers in Region 1 will plant/harvest approximately 10-14 days later than Region 2 and 21 days later than Region 3 in the fall. This is only intended to help make estimates if you are unable to reference the High Tunnel Planting Calendar for your region.

A final detail worth mentioning is that **strawberries** are botanically a perennial, but many commercial growers treat them as annual crops and refresh the production bed and replant after a season's harvest. The type of strawberries planted in a high tunnel are June-bearing. They perform best on black plastic. The planting calendar schedule reflects that practice

Additional Resources

Greenhouses, High Tunnels, & Low Tunnels
www.uky.edu/ccd/production/system-resources/gh-ht
IPM Scouting Guide for Common Problems of High Tunnel and Greenhouse crops in Kentucky (ID-235)
http://www2.ca.uky.edu/agcomm/pubs/ID/ID235/ID235.pdf
High Tunnel Blackberries and Raspberries (CCD-CP-8)http://www.uky.edu/ccd/sites/www.uky.edu.ccd/files/HTbrambles.pd
High Tunnel Strawberries (CCD-CP-61)
http://www.uky.edu/ccd/sites/www.uky.edu.ccd/files hightunnelstrawberries.pdf
High Tunnel Tomatoes (CCD-CP-62)
http://www.uky.edu/ccd/sites/www.uky.edu.ccd/files hightunneltomatoes.pdf
High Tunnel Leafy Greens and Herbs (CCD-CP-60)
http://www.uky.edu/ccd/sites/www.uky.edu.ccd/files hightunnelgreens.pdf

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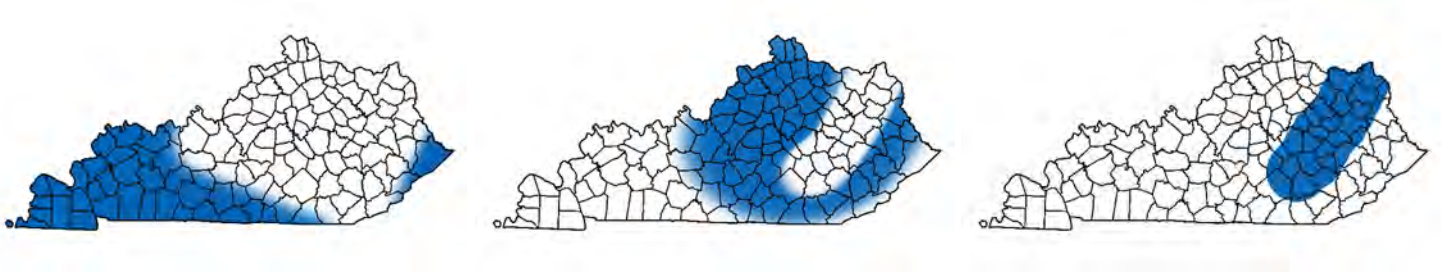

Figure 2. From left: Region 1, Region 2, and Region 3.

Reviewed by Christy Cassady and Brett Wolff, UK Extension Specialists
Graphics courtesy of Joshua Knight

January 2019

For additional information, contact your local County Extension agent

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HIGH TUNNEL PLANTING CALENDAR for ANNUAL CROPS

University of Kentucky College of Agriculture, Food and Environment
Cooperative Extension Service

CENTER FOR CROP DIVERSIFICATION

KADF KENTUCKY AGRICULTURAL DEVELOPMENT FUND

Kentucky Horticulture Council

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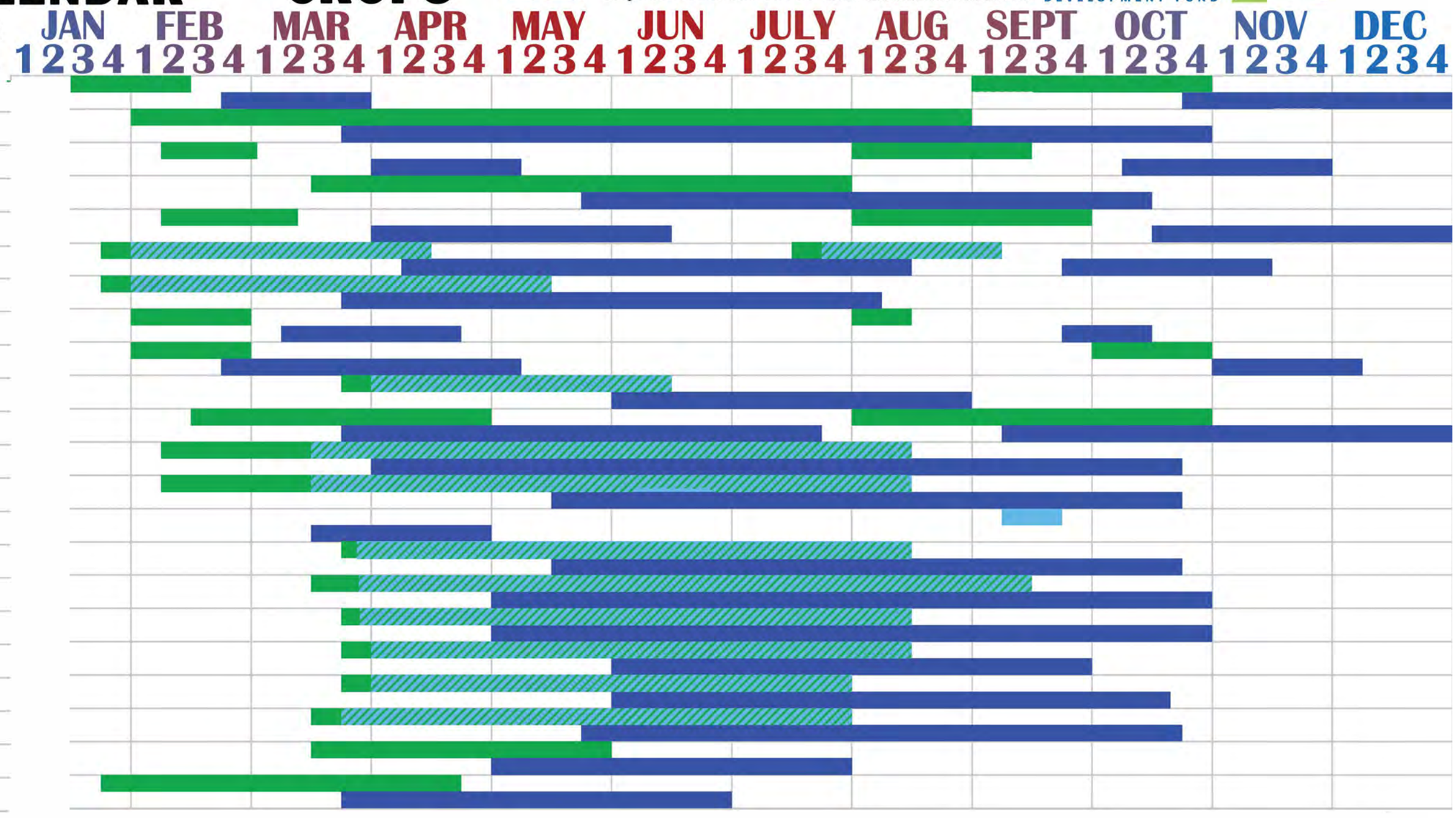
Resource 004 Back to My Spot

	AIR TEMPERATURE MIN	OPTIMAL
Spinach	20°	60° - 65°
Swiss Chard	40°	60° - 65°
Beet	50°	55° - 80°
Parsley[1]	45°	60° - 65°
Carrot	45°	60° - 65°
Cabbage[2]	40°	60° - 65°
Mustard Greens[3]	40°	60° - 65°
Turnip	40°	60° - 65°
Radish	40°	50° - 65°
Basil	45°	60° - 65°
Lettuce	25°	50° - 70°
Green Onion	45°	55° - 75°
Bulb Onion	45°	55° - 75°
trawberry	30°	60° - 80°
Cucumber	60°	65° - 85°
Summer Squash[5]	60°	65° - 80°
Melon[6]	65°	65° - 80°
Bell Pepper[7]	60°	65° - 80°
Eggplant	65°	70° - 90°
Tomato	65°	65° - 85°
Bean	50°	70° - 80°
	40°	50° - 65°

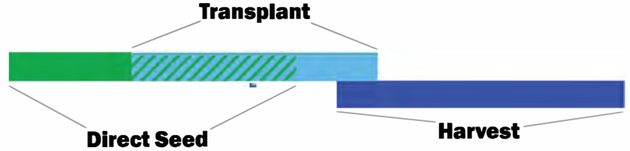


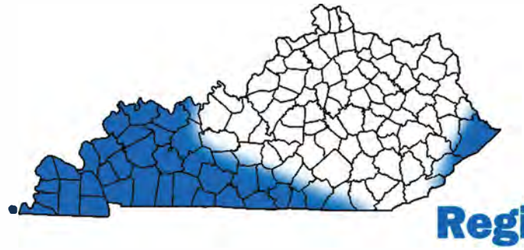
Plant Family

Beet Carrot Cole Crop Mint Sunflower
Garlic Rose Gourd Nightshade Pea

Alternative Crops

1) Cilantro, Dill
2) Chinese Cabbage, Pac Choy
3) Arugula, Collards, Kale
4) Leeks
5) Zucchini
6) Cantaloupe, Muskmelon, Honeydew, Watermelon
7) Sweet Pepper, Chile Pepper





Region 1

HIGH TUNNEL PLANTING CALENDAR for ANNUAL CROPS

University of Kentucky College of Agriculture, Food and Environment
Cooperative Extension Service

CENTER FOR CROP DIVERSIFICATION

KADF KENTUCKY AGRICULTURAL DEVELOPMENT FUND

Kentucky Horticulture Council

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Resource 005 Back to My Spot

	AIR TEMPERATURE MIN	OPTIMAL
Spinach	20°	60°- 65°
Swiss Chard	40°	60°- 65°
Beet	50°	55°- 80°
Parsley[1]	45°	60°- 65°
Carrot	45°	60°- 65°
Cabbage[2]	40°	60°- 65°
Mustard Greens[3]	40°	60°- 65°
Turnip	40°	60°- 65°
Radish	40°	50°- 65°
Basil	45°	60°- 65°
Lettuce	25°	50°- 70°
Green Onion[4]	45°	55°- 75°
Bulb Onion	45°	55°- 75°
Strawberry	30°	60°- 80°
Cucumber	60°	65°- 85°
Summer Squash[5]	60°	65°- 80°
Melon[6]	65°	65°- 80°
Bell Pepper[7]	60°	65°- 80°
Eggplant	65°	70°- 90°
Tomato	65°	65°- 85°
Bean	50°	70°- 80°
Pea	40°	50°- 65°

Plant Family

Beet Carrot Cole Crop Mint Sunflower
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Alternative Crops

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2) Chinese Cabbage, Pac Choy
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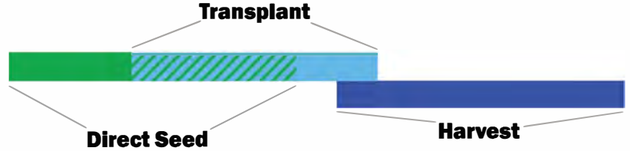
7) Sweet Pepper, Chile Pepper



Region 2

HIGH TUNNEL PLANTING CALENDAR for ANNUAL CROPS

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Resource 006 Back to My Spot

	AIR TEMPERATURE MIN	OPTIMAL
Spinach	20°	60°- 65°
Swiss Chard	40°	60°- 65°
Beet	50°	55°- 80°
Parsley[1]	45°	60°- 65°
Carrot	45°	60°- 65°
Cabbage[2]	40°	60°- 65°
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Turnip	40°	60°- 65°
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Basil	45°	60°- 65°
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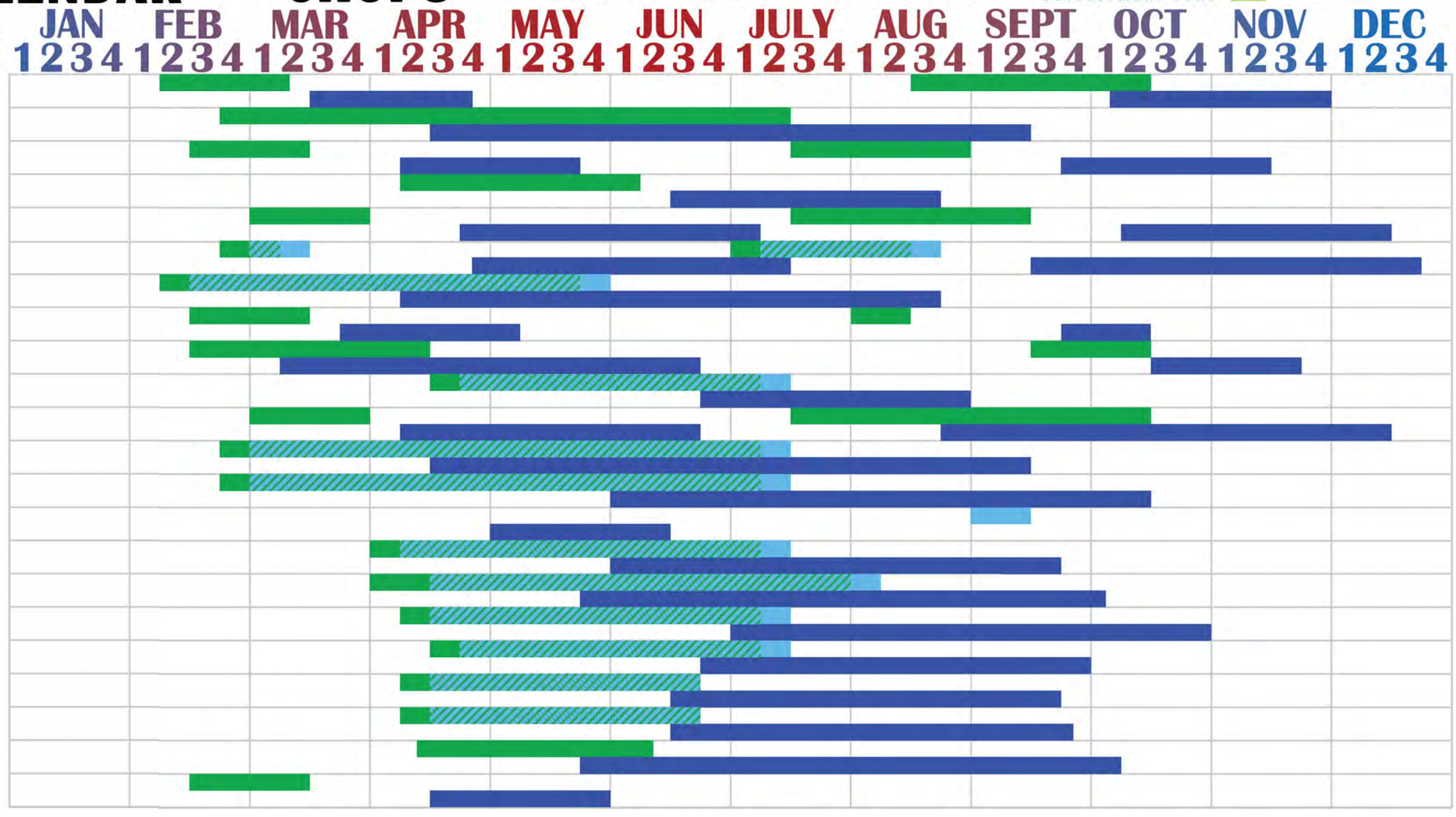
Eggplant	65°	70°- 90°
Tomato	65°	65°- 85°
Bean	50°	70°- 80°
Pea	40°	50°- 65°



Plant Family

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Garlic Rose Gourd Nightshade Pea

Alternative Crops

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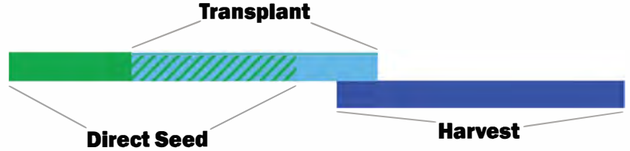

Region 3

University of Kentucky
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High Tunnel Economics

Matt Ernst[1]

Introduction

Growing produce in high tunnels is a common practice among growers supplying vegetables and fruits for local and regional markets. High tunnels provide growers the ability to extend the season beyond what is normally possible in open field production systems. The physical barrier of a high tunnel can also provide pest and disease management advantages. High tunnels have increased in popularity with the expansion of local and regional food systems in Kentucky. Some agricultural policy and program initiatives, such as the High Tunnel System Initiative in the USDA-NRCS Environmental Quality Incentives Program (EQIP), have aided new high tunnel producers.

The cost of establishing a high tunnel is modest compared to an automated glass greenhouse. Various cost-share and grant programs may also make high tunnels attractive to produce and flower growers. However, even with potential offsets in establishment costs, high tunnels require annual investments to successfully grow crops and maintain the structure. Furthermore, high tunnels are labor-intensive and require good horticultural practices and thoughtful management.

Generating economic estimates for high tunnel profi - ability can be challenging as each farm's site is unique. High tunnel establishment and labor costs may vary greatly between farms and regions, resulting in variable profitability of high tunnel crops. This fact sheet outlines economic considerations for high tunnels in general terms. The principles here may be applied across crops and high tunnel designs, from smaller self-designed tunnels to large tunnels constructed by professional crews.

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This fact sheet is best used as a resource to inform a grower's own cost and return estimates for growing crops in high tunnels. This is not a production guide. Consult other reliable resources to design and select a high tunnel structure and to make production decisions appropriate for each farm.

Yield and Price: The Keys to Maximizing Returns

- Higher yields of marketable produce per plant or per square foot, compared to field-grown production, are key to high tunnel profitabilit .
- High tunnel profitability is very sensitive to price. Premium selling prices for crops grown in high tunnels are key to sustaining profitable high tunnel production.

Some of the benefits of growing specialty crops in high tunnels are season extension (harvesting the crop before or after the traditional local open field growing season) and a higher percentage of marketable yields. However, there are upfront costs in order to reap these rewards. Most tomato varieties grown in a high tunnel, for example, require more labor on a plant-by-plant basis

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than tomatoes grown in the field. This is because of more production labor, especially harvest labor, as high tunnel tomatoes may yield more per plant.

Higher yields should provide the grower with a greater amount of marketable produce. This should translate to higher revenue on a plant-by-plant or space (per square foot or per acre) basis. Based on high tunnel production history in Kentucky and similar growing regions, high tunnel produce must also be sold at steady and premium prices to cover all the costs of production and to contribute toward the cost of the high tunnel itself.

A *sensitivity analysis* looks at how the changes in key enterprise variables would impact the overall profitability of an enterprise. Profits from fresh vegetables, fruit, and flowers are impacted by marketable yields and the prices at which those yields may be sold.

The table below illustrates the differences in returns from high tunnel tomatoes when sold at different prices and yields. The Cornell University interactive high tunnel budget tool (http://blogs.cornell.edu/hightunnels/economics/sample-budgets-spreadsheets/) was used to conduct this sensitivity analysis. Production assumptions and input prices were adjusted for a Central Kentucky production situation with 200 tomato plants grown in an unheated high tunnel. The budget assumed that 70 percent of the tomatoes would be sold at full retail price; 25 percent would be sold for $1 per pound; and 5 percent would be composted as culls.

The assumptions for retail prices were based on three-year average tomato prices reported from Kentucky farmers markets found on the CCD website at https://www.uky.edu/ccd/pricereports/KYFM.

Prices may not be constant throughout the season, especially if a high tunnel will bring products to market before the usual local season. For example, customers may be willing to pay a price premium if there are no tomatoes usually available during the first four weeks of a local farmers market. Consulting local and regional price reports can also indicate potential price trends.

The table reports returns to management, which includes a $550 annual depreciation cost for the high tunnel. Return to management is the return to the grower after all variable costs and fixed costs have been counted. This includes production input costs (the cost of plants, fertilizer, pest control products, etc.); harvest costs (hired labor, containers, transportation costs to market, selling expenses). These variable costs will change based upon the number of plants grown and the total yield; for example, it will take more labor hours to harvest and market 2,000 pounds of tomatoes than 1,600 pounds. The return to management also accounts for fixed costs, costs that do not change according to the quantity produced.

Another way to understand the return to management is as the amount a grower earns for his or her management, or the time that is not directly spent in growing and marketing the high tunnel crop. Successful high tunnel production involves pre-plant planning, developing a marketing plan and many other management activities that take time. If a grower has spent 40 hours in planning and managing high tunnel production, the return to management can be divided by 40 to estimate the hourly return. Using this assumption, a $1.50 retail price returns $3.83 per hour to management at a yield of 2,000 pounds. Return to management increases to $21.33 per hour at the $2.00 price, and a return of near-

Sample High Tunnel Sensitivity Analysis: Returns to Management*

Retail Price	1,600 lbs	1,800 lbs	2,000 lbs	2,200 lbs	2,400 lbs
1.5	-318	-83	153	388	623
1.75	-38	233	503	773	1043
2	243	548	853	1158	1463
2.25	523	863	1203	1543	1883
2.5	803	1178	1553	1928	2303

*Based on 200 tomato plants grown in an unheated high tunnel in Kentucky at various yields and prices; 70% sold at retail, 25% at $1/pound, 5% culls. Assumes annual fixed costs (including tunnel depreciation) of $ 50.

ly $39 per hour of management is estimated when the retail price is $2.50 per pound. Growers should develop yield and price projections for the high tunnel cropping system before starting high tunnel construction.

Understanding and Estimating High Tunnel Construction Costs

- Account for total construction costs of high tunnels, including potential "surprises" like site preparation and additional systems (heating/ventilation) expense.
- Estimate realistic construction labor costs.

One difficulty in estimating high tunnel profitability is that high tunnels can be as diverse as the farms that use them. For example, two farms could construct high tunnels of the same size and the same materials. But if extensive grading and drainage work are required at one site, construction costs could rise substantially. Similarly, if one farm were installing more heaters to use the high tunnel for growing transplants or off-season production, those heaters would also increase total construction costs.

Producers may also need to account for the cost of getting high tunnel materials to the farm. In some cases, freight costs can add a substantial percentage to high tunnel construction.

Here are questions to consider when estimating high tunnel construction costs:

- What will the raw materials cost?
- What site preparation work will be needed?
- What new systems equipment (ventilation, heating, irrigation) will need to be purchased?
- Will new equipment (like transplant production supplies) or machinery (bedding equipment, planting equipment, mulch layer) be needed?
- How much hired labor will be required for high tunnel construction?

High Tunnel Production Economics: Counting all Costs (including Labor!)

It has already been stated that the construction requirements for each high tunnel may be as unique as each individual farm. The same may be said for high tunnel production costs. The different types of crops, number of months the high tunnel is in use, crop rotations, soil fertility and even pest and disease management can all

result in production costs that can vary between seemingly identical high tunnels.

Labor costs may vary widely. Different crops and different production systems can involve very different labor costs. For example, the labor required to manage weeds by hand-weeding or hoeing in a high tunnel will likely be much greater than the labor needed to judiciously spray an approved herbicide over the same area. Different crops will also require different amounts of labor. The amount of labor needed for harvest on a per square foot basis will vary widely between lettuce and tomatoes, cucumbers and berries, flowers and culinary herbs

Two areas of labor often unanticipated by producers new to high tunnel production are crop scouting and ventilation. The intensive cropping system and confined production space in a high tunnel means that producers must closely monitor crops and have someone nearby to ventilate the tunnel on sunny days.

Efficient use of space is another factor impacting high tunnel profitabilit . For example, the production area next to the high tunnel sidewalls is wetter and cooler during the winter months. This may limit production options; the producer may decide to keep winter production to a minimum in those areas. This can impact the overall profitability projection. A related concern is plant populations. Tighter plant spacing in high tunnels could increase yields but could lead to more pest and disease management challenges because of humidity.

Pest and disease management can also create unanticipated costs. Rodents and wildlife are attracted to the warmth of high tunnels during cooler months, and the costs of managing such pests should be accounted for

during the high tunnel budgeting process.

Crop rotations are another factor creating variability in high tunnel profitability estimates. If crop rotations are not followed, disease may limit productivity of certain crops. Once in the soil, many soilborne diseases can persist for years. Similarly, soil health concerns can also be a limiting factor. Productivity can also be impacted by accumulation of salts, which can result from covered soil not experiencing leaching from precipitation.

Season extension, a main benefit of high tunnel production, also raises economic considerations. Supplemental heat, needed to harvest some crops for early market windows, may add additional costs. Producers should determine whether early season price premiums will be great enough to cover any additional costs of production. Non-financial factors, like day length requirements for cold-season tomato production, could impact crop yields and financial returns. These types of questions are essential when projecting the economic feasibility of season extension.

Conclusion

The purpose of this publication is to assist growers in considering the economics of high tunnel production: how to plan and project the costs and returns of resources used to grow food and ornamental crops in high tunnels.

Developing a cost and return projection is a recommended exercise for any new farm enterprise. Producers considering high tunnel production should list the possible returns and expenses, thinking through what production challenges will occur from week to week.

Several interactive high tunnel budgets, which may be adjusted and changed to reflect the likely costs and returns in Kentucky production situations, are available from extension services in other states. Links to some of these are listed below.

References and Additional Reading

- Bullen, Gary. "High Tunnel Budgets" (NC State University, 2009) https://cefs.ncsu.edu/wp-content/uploads/hightunnelbudgets02172009.pdf?3106e7
- "Marketing and Economics." (Various publications and presentations) http://hightunnels.org/category/for-growers/marketing-economics/
- "Where's the Money in High Tunnel Production?" (Cornell University, 2008 newsletter article) https://cpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/5/91/files/2016/04/where_is_the_money_shaw_opjr8a.pdf

Budgets

- Cornell Budgets (2009 season but in interactive spreadsheet for updating) http://blogs.cornell.edu/hightunnels/economics/sample-budgets-spreadsheets/
- Cornell High Tunnel Bramble Guide http://www.hort.cornell.edu/fruit/pdfs/high-tunnel-brambles.pdf
- "High Tunnel Production: The Basics for Success and Three Case Studies on Profitability" (Universit of Maryland, 2013) https://extension.umd.edu/sites/extension.umd.edu/files/_docs/publications/FS-95_High Tunnel production.pdf
- "Growing Under Cover: Guide to Polytunnel Options for Kansas Growers" (Kansas Rural Center, 2014) https://kansasruralcenter.org/growing-under-cover/
- Vegetable Production Budgets for a High Tunnel (Iowa State University Ag Decision Maker, 2013) https://www.extension.iastate.edu/agdm/crops/html/a1-23.html

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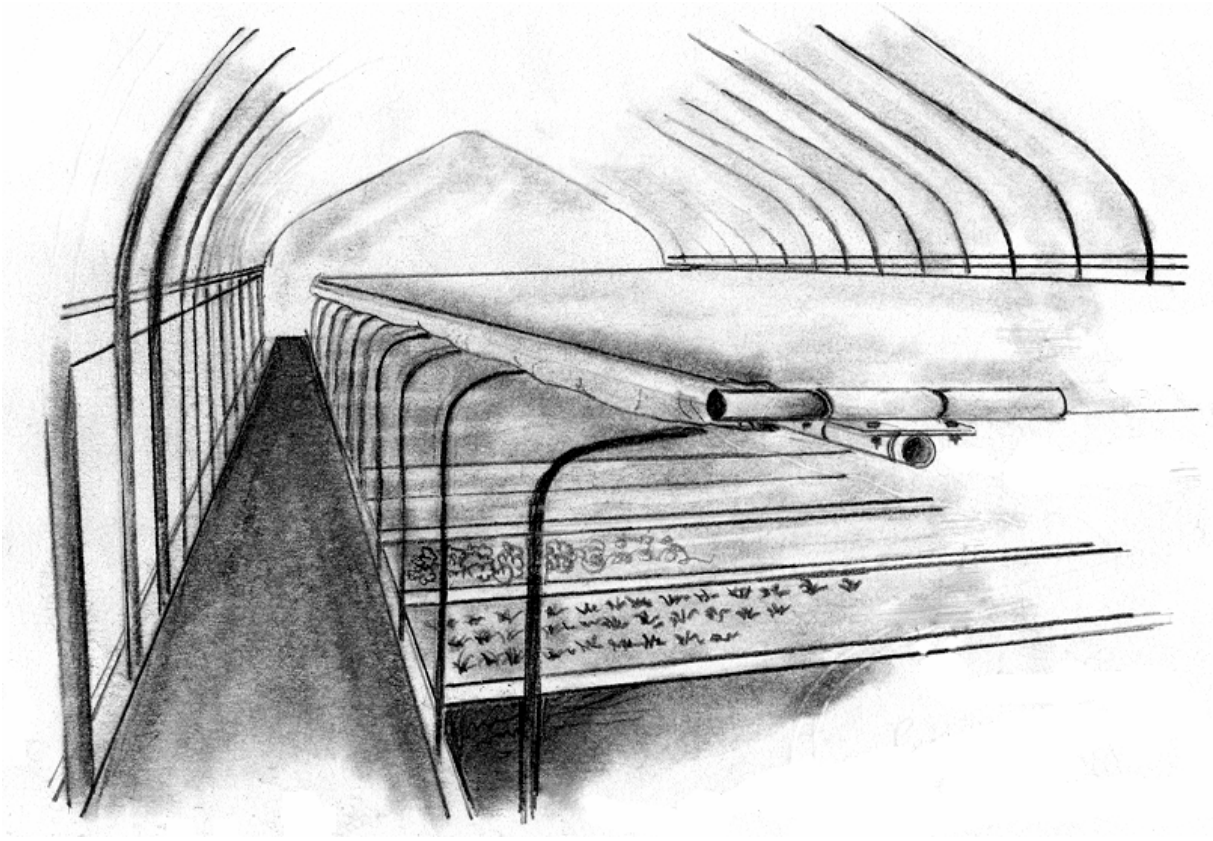
High Tunnels

Using Low-Cost Technology to Increase Yields, Improve Quality and Extend the Season



By Ted Blomgren and Tracy Frisch

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High Tunnels

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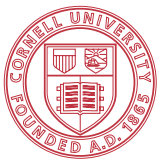

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Introduction

High tunnels are inexpensive, passive solar structures designed to extend the growing season and intensify production. By protecting crops from potentially damaging weather conditions (frost, temperature fluctuations, precipitation, wind, or excess moisture that delays planting or cultivation), high tunnels also reduce risk and enhance the quality of the harvest. They enable farmers to tap discerning markets hungry for local products and thus become more profitable.

High tunnels have other benefits. They can help farmers better utilize labor by providing work in bad weather and potentially creating year-round positions. Due to the protected microclimate inside the structure, high tunnel crops tend to be of higher quality and produce higher yields than field-grown crops. As plants inside high tunnels tend to experience less disease and insect pressure, fewer pesticides are used.

High tunnels—simple, plastic-covered, tubular steel structures—rely mainly on the sun's energy to warm the soil and air. Their name is derived from the fact that they are high enough in which to stand up. European and Asian farmers have used high tunnels for decades but this low cost growing environment is relatively new in North America. In recent years, more and more farmers are experimenting with their use.

Typically high tunnels forgo mechanical systems such as heaters, fans, and lights. Partially because of the absence of these amenities, high tunnels are less costly to build. Often, however, their frames are identical to more conventional greenhouses. Because high tunnels are far less capital intensive than greenhouses, it usually takes less time for them to pay for themselves. In addition, high tunnels are typically classified as temporary agricultural structures for purposes of property assessment and taxation, since they lack a concrete foundation or footings.

Co-author and Pennsylvania farmer Steve Moore suggests several rules for high tunnel design:

- Capture as much natural solar energy as possible.
- Conserve as much energy as possible.
- Keep it simple, both mechanically and managerially.
- Design and operate for minimal economic risk and a quick payback.

Unlike greenhouse culture, where crops may be grown hydroponically or in flats or pots on benches, crops in high tunnels are almost always grown in the ground. High tunnels can be configured in a variety of shapes (i.e., Quonset or gothic) and sizes (narrow or wide, short or long, single bay or multi-bay), and can be semi-permanent, temporary or movable structures.

There are also differences between four-season high tunnels (also called "hoop houses" or "passive solar greenhouses") and three-season high tunnels such as Haygroves. Four-season structures—the conventional single bay high tunnel—typically cost about \$2 to \$3/ ft^2 compared to \$0.75 to \$1.25/ft^2 for a three-season high tunnel. The farmer case studies and text that follow will illuminate the differences between these two types of structures.

In the Northeast, high tunnels are well suited for the production of high value crops including salad mix, baby spinach, fresh market tomatoes, cucumbers, red peppers, basil, cut flowers, raspberries, strawberries, and more. And dwarf tree-crops like sweet cherries can be produced in larger multi-bay tunnels (like Haygroves). Farmers may construct high tunnels to complement their existing agricultural operations or turn to high tunnels as the centerpiece of a new stand-alone business.

While we want to demonstrate how high tunnels may be a reasonable option for farmers wanting to extend their growing and marketing seasons, high tunnels are not for everyone. They are tools, not ends in themselves. To be an appropriate investment, high tunnels must suit a farmer's goals and resources. Each grower needs to critically examine the pros and cons of high tunnels in the context of their own situation.

Some farmers have no interest in extending the season. A couple farming at Persephone Farm in Oregon eloquently expressed this perspective (see the September 2006 issue of *Growing for Market*). They relish their off-season downtime and look forward to selling out and shutting down for the year. And they are cognizant and accepting of the trade-offs inherent in their decision.

This manual is intended to provide farmers, agricultural developers, and farm advisors with a realistic depiction of some of the applications for high tunnels in Northeastern agriculture. We aim to assist farmers and those who work with farmers in determining if and how to make use of high tunnels. As a decision-making aid, this publication provides both general principles and specific, in-depth examples as guidance. The manual should enable more farmers to use high tunnels effectively, enhancing productivity, net income, and quality of life, and avoiding some of the pitfalls of earlier adopters.

The information and concepts we have chosen to present are based largely on the observations and experimentation of farmers who grow in high tunnels in the Northeast from southern Pennsylvania to northern Vermont. We have profiled six farmers, and also have drawn from the experiences of several others. The extensive farming experience of two of the three authors has also provided much of the basis for this publication.

Case Study: Cramer's Posie Patch

Ralph Cramer and his son and business partner, Keith, are well-known southern Pennsylvania cut and dried flower farmers. They are also pioneers in the usage of multi-bay high tunnels. Ralph serves as the Eastern U.S. sales agent for Haygroves, manufactured in Great Britain. Their one acre of Haygrove high tunnels complements the other 49 acres of annuals, perennials (15 acres), and woody ornamentals (4.5 acres) that include 130 varieties of flowers at Cramer's Posie Patch.

Ralph Cramer's parents, Lewis and Mary, were also Lancaster County farmers. Lewis teased his wife Mary about her "little flower growing hobby" so she began to keep records of the profit from her flowers and (unbeknownst to him) his tobacco. The next year, when he saw the figures, he wasn't laughing anymore, said Keith. The couple developed several famous lines of cockscomb that their son and grandson continue to raise and sell as improved varieties.

Ralph bought an additional farm in another part of the county and continued to grow flowers on its silty loam fields. Land quality is very good on this current site, and two streams allow for overhead irrigation of direct seeded annuals when rainfall is low. However, compared to the old farm perched on top of steep hills, this farm is somewhat of a "frost magnet" with a shorter growing season, and the coldest field is also their wettest. The farm is classified as Zone 6B or a cold Zone 6, with fall frost around the first week of October and the last frost free date around May 15.

Before they purchased their first Haygrove, they were looking for some sort of multi-bay season extension structure. At a West coast meeting of the Association of Specialty Cut Flower Growers, the Cramers saw a homemade light-weight structure. Using it as a model, they built their own 1/6 acre tunnel, but a 20 mile per hour wind blew it down.

Keith explains why their experimental high tunnel failed. "The hoops in our homemade structure were made from rebar inserted through PVC pipe (to protect the plastic from rubbing), but the rebar was not strong enough to resist the wind pressure. We also had aligned our tunnels in a North/South configuration—which placed them sideways to the prevailing winds, making them even more vulnerable. We had no experience or advice about venting tunnels to prevent damage. We had no top rail or gantry of any type, thus the ropes could not be pulled tight to prevent the plastic from shifting and becoming a spinnaker in the wind."

Primed to grow in a multi-bay high tunnel, the Cramers discovered Haygroves and they traveled to England to see where they were commercially available. The structure impressed them, as did the Haygrove company's responsiveness to farmers' needs and ideas.

By enabling them to sell cut flowers both earlier and later and greatly improving size and quality in some cases, Haygroves have boosted the Cramers' business far out of proportion to the growing space they cover. With these structures, the Cramers achieve larger blooms and greater stem length for certain species and protect their flowers from disease and wind injury.

For many years the farm had only sold dried flowers. But the market for dried flowers is "soft," and storing dried stock hurts cash flow and takes up considerable barn space. The Cramers had trialed fresh flowers as an afterthought, but wholesalers needed to see quantity. By 2001, four years after they decided to seriously grow fresh cuts, they accounted for more than half of total sales. Producing both fresh and dried flowers for different markets has given the Cramers a broader range of options than they previously had.

Most of the Cramers' fresh cuts go to 20 major wholesale florists in the mid-Atlantic, from New York's Finger Lakes region to Washington, D.C. Downward price pressures and the logistics of getting a truck into and out of the city by 7 A.M. have led them to avoid New York City buyers. A typical buyer will receive delivery of 20 buckets of flowers from Cramers' Posie Patch once or twice a week.

Working with large-scale wholesale buyers can be demanding. Early every morning, Keith faxes an availability list to these buyers. Each buyer's order becomes a cut list assigned to the farm's eight-person field crew. They cut, grade, and do quality control as piecework in the field. Availability lists are saved to guide planning for the next year's planting.

Bouquet makers who sell to big box stores like Costco are another category of buyer that take a significant volume of their flowers. For some flowers, these buyers are looking for different characteristics than the wholesale florists, providing the Cramers with a market for smaller stems.

Cramer's Posie Patch also ships dried flowers to designers and florists nationwide; sells seeds to commercial growers and three large seed companies (Gloeckner, Germania and Johnny's); and has a small, dried flower retail shop at the farm.

Large multi-bay tunnels make sense for the Cramers' production needs. With routine sales of 800 bunches at a time, they would rapidly clear out a single 30' x 100' high tunnel. Smaller, single-bay high tunnels are also less accessible for tractors and so require more hand labor.

The cost per square foot under cover is lower in Haygroves than in single-bay high tunnels. A one-acre Haygrove costs about $28,000 (2006 price), including shipping and polyethylene film and the Cramers expect 15 to 20 years of use.

The Cramers take full advantage of the ability to manage each high tunnel bay independently. This flexibility allows them to tailor venting, shading, and irrigation practices to the temperature and humidity requirements of individual crops that fill a bay. With some experimentation, they identified species that are especially rewarding for them to grow in Haygroves. These include cockscomb, sunflowers, chili peppers, lisianthus, dahlias, and hydrangeas.

Cockscomb (*Celosia*) is the hallmark flower of Cramer's Posie Patch. Keith's grandparents selected this seed, and he and his father continue to do. In two bays the farm grows cockscomb as a cut flower. Once *Celosia* plants are established, warm temperatures (80^{o}F) will promote flowering better than cool temperatures (below 50^{o}F). Height of cockscomb is significantly greater, 4' to 4-1/2' in the Haygrove versus 3' in the field. The Haygrove also permits harvest to begin around July 6, a month earlier than field-grown.

This four or more week harvest advantage and superior quality brings a price that is 30 to 40% higher ($4.15 per bunch versus the $2.95 bunch price). They have been able to maintain that high wholesale price for all cockscomb stems cut during the season, whether grown in the tunnel or the field. This represents a huge increase in profit.

Chili peppers grown in Haygroves have become an important element of the farm's product mix. High tunnels allow them to grow bigger peppers, early harvest, and 3' stems (compared to 14" or 16" for field-grown). In the tunnel most chili harvests begin in the first week of August rather than at the first frost (late September or early October) in the field. They grow the chilies in the warmest bay, which they vent less and irrigate more than the other bays.

In the Haygroves, the first sunflowers are harvested 3-1/2 weeks earlier. Local sunflowers are most in vogue in May, June and the first part of July, and early sunflowers help with perennial sales. The Cramers grow seven visually identical varieties of pollenless sunflowers with different maturation dates. Their early sunflowers get them in the door with their customers so they can sell other species of early field-grown flowers. They double crop sunflowers, so after the early crop is done, they remove the plants, make new holes in the plastic, and seed sunflowers for harvest after the frost.

During Hurricane Isabelle and other catastrophic wind and rain events, cut flower plantings in the Haygroves were barely affected. With their tunnels fully vented for the high winds, the tops kept approximately 80% of the soil dry. The tunnels diffused the wind as it moved through them. Straight line winds and saturated soil combined to level outdoor crops, including transplants on black plastic mulch. Sunflowers inside remained safe and sound while those in the field were uprooted.

The Cramers could not grow marketable lisianthus outside, but do so consistently in the Haygroves, where they raise 1/6 acre of the flower in four colors. This high-value, rose-like cut flower species requires prolonged cool temperatures to develop stem length but cannot tolerate frost. They moderate temperatures by keeping the lisianthus bay open unless frost threatens, covering the beds in white plastic to reduce soil warming, and using shade cloth. In the Haygroves, lisianthus stems reach 3' in length (versus 9" in the field). "My customers are not interested in anything shorter than 20-24" stems," says Keith.

Hydrangeas (*Paniculata grandiflora*) are the first woody perennial the Cramers have tried in the Haygroves. They have been rewarded with more rapid growth and impressively large flower clusters. The trial was so successful, the Cramers have added a full bay (approximately 600 plants) of the variety 'Limelight.'

Making the right decision about when to cover multi-bay high tunnels is critical in regions with the possibility of late snowfall. The Cramers want to get the biggest jump on production that they can. Yet if they cover the tunnels too early, they run the risk that a late snowstorm will damage the structure, as they are not engineered for snow load. In their southern Pennsylvania location, they generally cover the tunnels around April 7 and plant them in mid-April. In the Spring of 2003, the structure withstood 5" of wet, heavy snow. They were able to "bump it off" without incident.

They aim to 'hibernate' (remove) the tunnel plastic in mid-October. They bring the top poly from two adjoining tunnels into the shared leg row, cover it with black plastic row mulch to prevent UV degradation, and secure it with tomato twine. They remove the doors and store them in the barn. Over the winter, they leave the side curtains hanging on the structure.

The first year they grew in the Haygrove, the Cramers gave their crew responsibility for recording daily

high and low temperatures in each bay. This data taught them that the normal temperature fluctuation is okay. They monitor the tightness of the ropes monthly. During thunderstorm season, they keep the tunnel fully vented for temperature control, with doors open and the roof clipped in the open position. As this is also the proper way to vent for high winds associated with thunderstorms, storms require no special intervention.

Blessed with good Lancaster County soils, the Cramers use a one-size-fits-all fertilizer program, the same in the Haygroves as outside. They apply a 19-19-19 fertilizer at the rate of 50 pounds of actual nitrogen per acre. After incorporating the fertilizer, they chisel plow, disc and lay plastic mulch.

For their Haygrove plantings, the Cramers use a flat plastic bed layer to apply 5' wide plastic mulch over a 4' wide planting area. They can just fit four of these beds per 24' bay. These are not raised beds because their raised bed shaper/plastic layer cannot squeeze four beds into a bay. They vary the color of the plastic mulch depending upon whether they want to warm or cool the soil. Chiseling in the fall helps the soil dry out faster in the spring, when they do most of their soil preparation and the plastic mulch laying. They would like to fully prepare the beds in the fall but winter winds loosen the plastic mulch.

Only transplants, set by hand, are used in their Haygroves. First, to correctly space holes in the plastic mulch, they use the waterwheel from a transplanter behind a tractor. While transplants mitigate risk, they require much more labor. In contrast, in the field they direct seed about 80% of their annuals—with two acres of seeding scheduled every two weeks. Only about five acres of flowers are transplanted in the field.

As controlling foliage wetness is a major high tunnel benefit, the Cramers only use drip irrigation in the Haygroves. “We don’t want to make it rain inside a tunnel,” explains Keith. Using transplants makes it feasible to use drip tape. Were they to direct seed, they would need to cultivate, which would damage drip tape. They use double drip tape per bed.

Haygroves vent high and provide excellent air exchange, therefore humidity is not a problem. Alex Hitt, who grows organic heirloom tomatoes in Haygroves and in single-bay tunnels in Graham, North Carolina, attributes the reduced disease of plants in the Haygroves to their superior ventilation. The internal humidity is similar to outside conditions when vented.

Powdery mildew is more prevalent under the dry conditions common to these high tunnels. The Cramers sometimes have powdery problems in the field during dry periods of the season as well. *Oxidate* and *Zerotol* are hydrogen peroxide products that they have used successfully to control this disease. As an added bonus, these pesticides have zero re-entry periods. They prevent powdery mildew from spreading by exploding the spores so they can’t attach to plant tissue. Existing powdery mildew growth—which has a grey powdery look—is not affected by these products; therefore, detecting this disease problem early is essential as flowers with grey mildew are obviously not marketable.

Under the Haygroves (as with greenhouses), dry season pests like aphids and spider mites are accentuated. The structures offer a perfect micro-climate and protect these pests from rain washing them away. Keith relies on chemical pesticides to control these pests, such as the broad-spectrum organophosphate *Orthene* against aphids and several different miticides in rotation to avoid resistance.

In retrospect, the Cramers realize that a simple procedure would have eliminated weed pressure in the leg rows between bays. Before drilling the tunnel legs into the soil, they recommend making a shallow furrow (for runoff control) and pinning down narrow strips of black weed barrier fabric. In the absence of this prophylactic action, the Cramers apply *Roundup*. In the growing beds, plastic mulch eliminates the need for mechanical cultivation or herbicide applications, although some weeding must be done by hand in the plant holes.

Mid-weight floating row cover protects tender transplants coming from the greenhouse. Their crew lays this row cover over low wire hoops straddling the beds. Eventually, when the transplants outgrow the hoop, the row cover is removed. They use wide enough fabric to reach from one side of the bay to the other. When they pull it off, they move it to the center of the bay (keeping it out of the leg row where it could get wet), between the second and third beds.

These covers must be carefully managed to control excessive temperature and humidity. The Cramers learned the hard way. “The first year, we cooked over 4,000 sunflowers,” Keith recalls. In the spring, they can avoid excessive heat and provide adequate airflow just by opening the doors. A west wind keeps the air moving. When they have a stretch of cloudy weather followed by sun, they find it is important to remove the row cover and let the breeze in the doors. This dries out the plants’ micro-environment, preventing disease. It also hardens off the plants.

Haygrove recommends that the doors of the tunnel be aimed at the prevailing winds usually from the West. This satisfies ventilation needs

and protects the structure from severe winds. Many greenhouse designs suggest a North-South orientation for even sunlight on the plants because the trusses create quite a bit of shade. High tunnels have a lot less overhead steel to shade plants. Adequate light has not been an issue in the Haygrove tunnels.

The Cramers use shade cloth on lisianthus to reduce ambient temperature and elongate the stems by reducing light. Rather than covering the top of the high tunnel with shade net, they put it underneath—inside the tunnel. If it were outside, venting would become more difficult. Keith explains, "Our shade net is rolled out on top of ropes that we tie across the bay. They are approximately 7 feet above the soil, so we can walk under them. If needed, we can move the shade across the bay and store on the north side to give full sun to the crops."

After four years of use, the Cramers are replacing their polyethylene cover with an improved greenhouse film called Luminance. It is designed to deflect a portion of infrared rays, reducing the highest temperatures in the tunnel. Some light is lost with this feature so to offset the loss, Luminance diffuses light, sending the available light into the plant canopy at different angles.

Cramer's Posie Patch faces some difficult choices in charting its future course. One weak link is labor. Eight Mexican laborers legally brought into the country on the federal government's H-2A Agricultural Guest Worker Visa Program constitute the farm's field crew. Keith tolerates the program's "red tape nightmare because it provides the qualified, legal, dependable workers needed to operate profitably." To add more workers would require building more housing, and adding septic, electric, and other infrastructure. Alternatively, they could reduce outside production and rely on fewer workers.

Haygrove Tunnels have fit nicely with the farm's recent shift in emphasis to fresh cut flowers. The novelty of having local flowers earlier than other area growers makes the Cramers popular with the major wholesale florists they supply. Being the first local grower with certain crops creates a definite customer loyalty. At the end of each season, most of his customers tell Keith, "Don't forget me next year when you have the early stuff!"

Enterprise Budget for Cockscomb in One Bay (1/6 Acre) of a One Acre Haygrove Tunnel at Cramer's Posie Patch

Fixed Costs		
Construction Costs	**Materials**	**Labor**
High tunnel construction		$3,000
High tunnel frame	$25,000	
Subtotals	**$25,000**	**$3,000**
Total Construction Costs		**$28,000**
Fixed Costs		
High tunnel construction (divided by 15 years)		$1,867
Interest (construction financed at 7% for 15 years)		$980
Taxes, land, office expenses, fees		$222
Total Fixed Costs		**$3,069**
Total Fixed Costs per Bay (1/6 Acre)		**$511**
Variable Costs per Bay (1/6 Acre)		
Materials and Machinery		
Seeds and growing out plugs		$357
Fertilizer, lime and compost		$10
Irrigation supplies		$68
Plastic mulch and row cover		$90
Pesticides		$70
Poly covering (divided by 4 years)		$200
Delivery costs		$230
Subtotal		**$1,025**
Labor Costs ($11/hr)		
Cover installation and removal		$110
Bed preparation and fertilization		$22
Transplanting, laying drip tape and mulch		$380
Pruning, trellising, irrigating, spraying, venting		$220
Harvesting, grading, packing		$2,400
Sales and delivery ($14 to $20/hr)		$366
High tunnel clean-up		$132
Subtotal		**$3,630**
Total Variable Costs per Bay		**$4,655**
Total Costs per Bay		**$5,166**
Revenues per Bay*		**$20,125**
Net Returns per Bay		**$14,959**

*Revenues are based on a harvest of 4,800 bunches per bay and a selling price of $4.15/bunch (plus a total of $105 in delivery fees).

Prior to the first fall frost, the Cramers' customers start to look to other suppliers in California, Holland, and South America. The uncertainty of the first frost date is a concern for their customers since they need to have a continuous supply of flowers. The summer season is very intense for all involved, with daily availability updates and a compressed schedule. Keith says that most of his customers look forward to the more relaxed environment of standing orders, even though the product is not quite as nice or nearly as fresh.

Timing the late season crop is an on-going challenge since the hard frost is unpredictable.

Moreover, by the time that hard frost ends the harvest, the wholesale market has weakened so it is difficult to get the higher prices needed to justify tunneled production. With only an acre of tunnels, the Cramers cannot protect both the quantity and diversity of product that their wholesalers demand. For these reasons, the Cramers have decided concentrate on getting a jump on the harvest early, rather than keeping it going after the fall frost.

Case Study: Weaver's Orchard

Weaver's Orchard in Berks County, Pennsylvania is a third generation, 100-acre family farm. Like many tree fruit growers trying to survive in today's competitive environment, Ed Weaver believes in diversification and direct marketing. The farm grows a number of fruits and vegetables to complement the primary crop of apples. The farm's on-site market has become a primary sales outlet and the farm offers a pick-your-own option for small fruits (such as blueberries, strawberries, and brambles) and for peaches, apricots, plums, nectarines, cherries, apples, and pears. With these features to attract a good clientele to the farm, the business is able to sell half of its farm's production retail.

Ed's grandparents purchased the farm in the 1930s where they grew vegetables, fruits, and tobacco. Under Ed's management, the farm produced tree fruit, vegetables, and strawberries until ten or twelve years ago, when he added blueberries and brambles.

Sweet cherries have been an important crop on the Weaver Farm for three decades. In the late 1990s, frustrations with standard rootstocks convinced Ed to expand their acreage with new dwarfing rootstocks. The dwarf trees come into full production much more quickly and are easier to manage. But when his first dwarf trees began producing, cherry yields were hurt by frost, rain, and birds. The damage was so great that Ed decided he had to find a way to protect the crop or else remove the trees.

Searching for a way to protect the trees led the Weavers to discover Haygrove multi-bay high tunnels at a spring 2003 trade show. Subsequently, Ed took a growers' tour to England to see how these tunnels are used on another continent. Full of enthusiasm, that spring the Weavers constructed their first multi-bay tunnel over seven-year-old dwarf sweet cherry trees. The three-bay tunnel covered 0.6 acre; each bay is 28' x 300'. In 2004, the Weavers constructed a 0.9 acre Haygrove over five-year-old cherry trees. These tunnels were longer, with two 28' x 450' bays and one 20' x 450' bay. Each bay accommodates two rows of trees, spaced 9' apart in the row and 15' between rows.

In two years, the Weavers had put almost one-third of their sweet cherries under plastic. Later, they added more Haygrove tunnels for growing tabletop strawberries, brambles, blueberries, and 1/3 acre of tomatoes.

During some years, Haygrove tunnels can mean the difference between an abundant high quality crop and virtually no crop. On this southeastern Pennsylvania farm, losses might reach as high as 90% in the uncovered orchard blocks, while only 2 or 3% of the crop is lost on trees protected by the Haygroves.

Cherries remain one of Ed's most promising crops under plastic. Beyond affording protection from adverse weather and birds, they offer other significant benefits. For a number of reasons, cherries grown under Haygroves tend to have higher fruit quality. Their quality also lengthens shelf life.

The Haygroves' minimal frost protection has been enough to protect the earliest varieties, which flower when temperatures can still drop below freezing. These structures can advance the ripening of early cherry varieties up to one week. And earliness can raise the price 30 or 40 cents a pound or more.

Rain is an important risk factor for a delicate fruit crop like cherries. Excess rain at or near harvest time is a major cause of crop loss in the uncovered cherry blocks. Rain-induced cracking and disease makes cherries unmarketable. Rain at the wrong time also causes other problems in the field.

Keeping rain out with the tunnels and using drip irrigation to even out moisture levels has been an effective solution. High tunnel coverage provides insurance that the orchard will provide a consistent supply year after year, which is no small matter when it comes to retaining its place in the market.

The multi-bay tunnels make it possible to leave cherries on the tree longer, so they can reach optimal size and maturity. For uncovered cherry plantings, a grower's only defense against the threat of rain has been to pick early. Staying on the tree longer makes the cherries sweeter and bigger. Ed Weaver estimates as much as a 20% potential weight gain in the tunnel-grown cherries harvested. This enhanced yield helps pay for the costs of the tunnels. On the other hand, increased heat under cover around harvest time can soften cherries and reduce their quality, so proper venting of the tunnels is crucial.

Bad weather ordinarily prevents farm tasks from being performed in a timely fashion and interrupts harvest. However, inside the Haygroves, farm employees can work even when it is raining or wet. Similarly, the rain is less of a deterrent for U-pick customers when they can harvest cherries under cover.

In addition to protecting the fruit from disease by keeping off precipitation and preventing lingering wetness, Haygroves have also reduced bacterial canker at Weaver's Orchard. This disease organism can enter pruning wounds. The Weavers prune their

trees following the cherry harvest and leave the Haygroves covered until late August, after the wounds have healed.

Plastic bird netting around the perimeter of each tunnel—to close off the sides and ends—is sufficient to keep birds out of the trees. Bird damage and consumption in an average year destroys about 15 to 20% of the cherry crop outside of the tunnels and, in a dry year, bird damage can be greater.

Counter to these benefits are the ways that Haygrove structures complicate cherry production. Much of the work relates to the plastic itself. The structures must be covered each spring and uncovered in late summer. And the down side of keeping rain off a crop is the need to irrigate.

The Weavers use bumblebees to ensure pollination. Early flowering can occur when it is still too cold for honeybees to be active. And these bees can become disoriented in high tunnels. Honeybees fly repeatedly to and from their hive, while bumblebees spend the entire day away from their colony. Advance (six weeks) notice is required to order bumblebees and the timing of an order can be changed if blooms are slower than anticipated.

Erratic weather conditions call for more intensive tunnel management. Venting is fairly easy, but requires vigilance. If it gets hot or if a thunderstorm threatens, the Haygroves must be vented. When rain is forecast, the tunnels must be closed down.

It can be inconvenient to work around and inside the Haygrove structure and for a tree fruit grower, this disadvantage is magnified. Because the tunnels are 14' or 15' high at the peak, the cherry trees must be pruned back to 12'. Putting up Haygroves over existing trees is awkward, though doable.

The tunnels are spacious enough to drive a tractor inside for fertilizer application, spraying, and mowing. At Weaver's Orchard, a granular fertilizer is applied in early March, before the tunnels are skinned, so that precipitation will water it in. Growing season fertility is provided with fertigation. All watering is done with drip irrigation.

Weaver's Orchard is situated on rocky soil and the terrain is uneven. The soil and topography make erecting Haygroves or any other type of tunnel a challenge.

None-the-less, Ed Weaver believes that the Haygroves are paying for themselves. More importantly, these structures are allowing the farm to lessen the risk of crop loss and have profitable, high quality cherry harvest every year. He estimates that an increase in the value of the crop by just $0.40 per pound will pay for the annual cost of the tunnel over its lifetime.

Given the investment, Ed counsels other growers to maximize the efficient use of space in Haygroves. He was unable to do so with his first Haygrove structure as it was constructed over an existing cherry planting and that orchard block was not spaced at the optimal high density.

They have almost doubled tree density in the new blocks they are planting with the intention of covering them with Haygroves. Ed noted that new studies have demonstrated how cherry growers can intensify production by increasing the fruiting to vegetative wood ratio. They hope to develop more fruiting wood in each tree by paying more attention to tree training.

Yields depend a great deal on the variety. Rainier, a superior tasting variety, has performed at the top. It also commands a higher price and Weaver's Orchard sells pre-picked Raniers for $4.99 per pound, a dollar per pound more than dark cherries. They have 100 producing Rainier trees in their Haygrove (and none in the field). At 30 pounds of production per tree and 400 trees per acre, Ed extrapolated a yield of 12,000 pounds per acre and a $30,000 gross income at the pick-your-own price of $2.50 per pound. Ed estimates that this is about twice the outdoor yield of varieties that produce consistently. However, accurate comparisons with outside production are difficult, given differences in age and varieties.

On the other hand, about half of the Weavers' trees in the 2004 Haygrove tunnels s are varieties that are especially challenging to pollinate. Even outside of the tunnels, these varieties characteristically produce a good crop only two years out of three. But in the Haygroves, their production was down a surprising 85% in 2005. By bringing in more bees and planting more varieties as pollinators in the block, they are trying to address this problem. Recent releases of self-fertile varieties are also relevant. The shortfall in fruiting reduced yields by about $5,000 an acre (wholesale gross revenues) and cut net income by at least $3,500 per acre.

Despite some disappointing yields in the 2004 block, Ed remains optimistic about growing cherries in these multi-bay high tunnels. They have solved some otherwise intractable problems—most significantly those caused by rain and birds. And with several years of experience and investigation, he has good ideas about approaches to cultural practices, varietal selection, and planting density to overcome other snags in his plan.

Ed also is exploring the value of Haygrove production for other crops. Berries are important in the crop mix at Weaver's Orchard, though the Weavers are new to growing berries in Haygroves. Their protection from birds and rain has reduced damage and disease and improved quality for all types of berries. In the high tunnels, both the blueberries and brambles also produced "super

vigorous" canes heavy with fruit that required either temporary or additional trellising, respectively. Ed calls this "a good problem!" Blueberries ripened earlier (three to four days to a week or more) than field grown berries, but the farm did not gain much added value with earliness for this crop.

The Weavers have the least experience with bramble production in the Haygroves as their first crops under plastic were harvested in 2005. Summer and fall bearing bramble crops—Black Raspberry, Primacane Red Raspberry, and Floricane Red Raspberry—were successful. The biggest benefit is that the cover keeps the canes and fruit dry. Pickers don't have to wait until the dew has dried, and with fewer blemishes, the fruits are easier to pick. Shelf life has increased, with no mold evident a day after picking. Ed wonders, though, if the lower productivity of black raspberries, compared to reds, justifies the cost of planting in the Haygroves.

Ed has experimented with several strawberry production systems, including day-neutral varieties and June-bearing varieties in tabletop production. He is optimistic about growing tabletop strawberries, which are common in the United Kingdom. This system gives the grower flexibility in timing the fruiting of the crop. Plants are started in trays on pallets in another hoop house. At blossom, they are moved to the Haygrove. After production ends, they are returned to the other hoop house. Planting date, pinching primary buds, temperature, and the date the plants are moved to the Haygrove are among the factors the grower can manipulate to alter the harvest date.

By keeping rain off the plants with the tabletop system, the Weavers have been able to grow a June-bearing strawberry crop with a longer shelf life and no pesticide application. They retailed their crop for $1 more per quart. The Weavers' experience with ever-bearing (day-neutral) strawberries grown in the ground was less promising, as they were afflicted with disease problems. Ed Weaver is eager to experiment with growing strawberries that ripen out of season, in May, and in the Fall.

Enterprise Budget for Sweet Cherries in a One-Acre Haygrove Tunnel at Weaver's Orchard

Fixed Costs

Tunnel Construction Costs	**Materials**	**Labor**
High tunnel construction (220 hrs. x $10/hr)		$2,200
High tunnel frame	$25,000	
Irrigation	$630	
Subtotals	**$25,630**	**$2,200**
Total Tunnel Construction Costs		**$27,830**

Cherry Tree Establishment Costs	**Materials**	**Labor**
Trees (@ $10.25)	$4,100	$2,300
Stakes and guards	$1,312	
Fertilizer, pesticides, etc.	$237	
Subtotals	**$5,649**	**$2,300**
Total Cherry Tree Establishment Costs		**$7,949**

Summary of Annual Fixed Costs	
High tunnel construction (divided by 15 years)	$1,855
Interest (construction financed at 7% for 15 years)	$974
Taxes, land, office expenses, fees	$295
Cherry tree establishment (divided by 15 years)	$530
Total Fixed Costs	**$3,654**

Variable Costs

Materials and Machinery	
Fertilizer and lime	$47
Bees for pollination	$220
Pesticides	$244
Poly cover (divided by 4 years)	$1,000
Marketing Costs	$800
Subtotal	**$2,311**
Labor Costs ($8 to $12/hr)	
Poly cover installation, removal, venting	$1,200
Pruning, irrigating, spraying	$158
Harvesting, grading, packing	$3,706
Sales and delivery	$880
Subtotal	**$5,944**
Total Variable Costs	**$8,255**
Total Costs	**$11,909**
Revenues*	**$17,780**
Net Returns	**$5,871**

*Revenues are based on yields of 5,760 lb/acre and an average wholesale price of about $2.10/lb. The Weavers wholesale nearly half the total crop to their own farmstand, and then retail the cherries for an average of $4/lb, increasing their revenues by $1.90/lb, or by just over $4,200 (after marketing costs) in profits per acre. Because not all the cherry trees produced a full crop, yields were reduced by about 50%, having a large impact on net returns.

Case Study: Cedar Meadow Farm

Steve and Cheri Groff, and their three children, live in Holtwood, Pennsylvania, in southern Lancaster County. On rolling land near the Susquehanna River, they produce 210 acres of small grains and vegetables including no-till tomatoes, pumpkins, and sweet corn. Steve has become known for his success with a permanent cover cropping system in which he establishes vegetable crops without tillage and makes use of cover crops and crop rotations as a way to save soil, reduce pesticides, and increase profits.

Like many no-till farmers, Steve has noted that because soils remain colder under no-till conditions, they tend to produce later crops. Steve grows nine acres of no-till tomatoes, and his inability to capture the lucrative early market had been a frustration.

Steve had been growing some tomatoes in a 15' x 96' high tunnel for nearly seven years, and was pleased with the benefits a high tunnel offers including earliness, improved fruit quality, and increased yields. But he wanted to produce his early tomatoes on a much larger scale. So, four years ago, Steve built a one-acre, multi-bay Haygrove tunnel.

Steve's decision to purchase the Haygrove tunnel was based primarily on economic considerations. The initial cost of the structure, 6 mil plastic cover, and mulch, with about 250 hours of labor for assembly, was about $30,000. On a square-foot basis, that was less than half what a high tunnel would have cost him to build. Steve calculates the annual cost of maintaining his acre of Haygroves at $4,000. This figure includes one-third of the cost of the polyethylene film, which he replaces every three years, labor for covering the structure in the spring and uncovering it in the fall, and labor for venting.

Steve was also attracted to the scale of the Haygrove. One multi-bay unit would give him an entire acre of tomatoes under cover. Finally, he liked the fact that the structure was tractor-accessible, giving him greater flexibility to perform tillage and other operations with machinery.

Steve's tunnel has six bays that are 24' wide and 300' long. To maximize its use, Steve planted 6,000 plants in the first season, but the result was tall and leggy plants. He sought to control the vegetative growth by reducing nitrogen rates and watering, which did seem to retard growth but also resulted in smaller tomatoes.

The next year, Steve reduced the plant population to 4,800 plants per acre and was pleased with the results. In his first year, Steve planted into bare ground and had a difficult time with weeds despite using herbicides. In the second season, he formed raised beds and installed a woven plastic ground cover, which resulted in a warmer soil and effective weed suppression. He plans to maintain the beds permanently and to reuse the mulch and stakes.

Steve now makes weekly nitrogen applications through a drip irrigation system, and vents to control excessive growth. He irrigates three times each week, providing 3 pounds per acre of nitrogen per watering. In the past, he used calcium nitrate and liquid nitrogen. Now that he has established permanent, mulched beds, he will use a complete fertilizer beginning soon after planting.

Steve sets his plants out during the third week in April, and harvests from the first week of July until early November. So far, he has been pleased with the variety, *Mt. Spring,* finding that it performs well for a much longer period inside the tunnel than it does in the field, but also continues to trial other early varieties. In the future, Steve plans to use row covers inside the tunnel in early spring to extend the season even longer. He is also looking into options for supplemental heat as a means to prevent frost injury and to boost spring growth.

Steve has used bumblebees to get better pollination but questions if they are necessary, especially since he likes to occasionally vent on windy days to control plant growth and lower humidity.

In his first year, Steve had yields of 2,400 25-lb boxes (60,000 lb.) of #1s and #2s. In his second year—after fine-tuning crop spacing, fertilization, and irrigation—tomato yields increased to 3,400 boxes per acre, 70% of which were #1s. His four-year average annual yield for Haygrove-grown tomatoes was 71,531 pounds.

Steve's second season in the Haygrove tunnel was a particularly wet one, and yields of the same tomato variety in the field were only 1,200 boxes per acre. The three-fold increase in tomato yields was just one of the benefits of the tunnel. The quality of tunnel-grown fruit has been vastly superior to field-grown fruit. "We see it every time we bring high tunnel tomatoes into the grading room and compare them with field-grown tomatoes," says Steve.

Steve has found the effects of severe weather and disease pressure to be noticeably reduced inside the tunnel. He sprays occasionally, finding that he gets good coverage by using an air-blast sprayer from both ends. The natural movement of air inside the tunnel helps deliver the pesticide to plants in the middle of the structure. Last year, Steve struggled with a bacterial problem, and is re-evaluating

his use of the permanent ground cover and stakes that may harbor the pathogen over the winter. He has also struggled with spider mites, and is seeking an alternative to miticides for their control.

Although Steve is experimenting with raspberries in one bay of the tunnel, he is not planning on rotating out the tomatoes. He has considered relocating the tunnel if he finds that tomato pest populations increase to unfavorable levels, but he estimates that may cost up to $4,000. He believes that the experience of erecting the tunnel the first time will enable him to reduce the time required to build the tunnel a second time from 250 hours to about 200 hours.

Since Haygrove tunnels are not designed to withstand more than a few inches of snow, they were a good choice for Cedar Meadow Farm as Steve wasn't looking for an over-wintering structure. He wanted to begin production after snowfall was no longer a threat, and finish the season before winter. To prepare for winter, he removes the sheets of plastic, placing them in the gutter of every other bay, a job that takes about 20 labor hours to complete. He wraps them in black plastic to prevent decay from ultraviolet radiation.

Installing the plastic in the spring is a big job. Six people can do it on a calm day, but eight is better, especially if it becomes breezy. Steve says that the key is to be prepared for that calm day when plastic installation will go smoothly. He estimates that installing the plastic cover and end-wall doors takes about 50 labor hours every spring.

Once the tomatoes are planted, it is important to ventilate the tunnel properly, which Steve describes as an art that comes from experience. "You have to make venting decisions based on temperature, wind speed and direction, and the stage of crop growth," he said. "During initial fruit-set—the most critical time—I look at the hourly forecast on the Internet. During that six-week period, I literally baby-sit the tunnel."

Like other high tunnels, multi-bay units are ventilated manually, but instead of rolling up the sides and ends, the plastic on a multi-bay is pushed up, and held in place by adjusting the tension on the ropes that hold the plastic down. During the early season, when days are warm and nights are cold, ventilation is time-consuming. Steve estimates that ventilation takes from 15 minutes to two hours of his time every day for the first six weeks of the season.

Beginning around June 15, Steve opens the tunnel and removes the doors for the rest of the season. If high winds are expected, Steve fully vents the tunnel, as Haygrove recommends, to avoid damage to the structure. When properly constructed, these tunnels are designed to withstand 70 mph winds. Steve had some experience with high winds—in the field, tomatoes and sweet corn had blown down but his tomatoes in the multi-bay tunnels remained unscathed.

Steve believes that he has realized his objectives with the Haygrove tunnel. He has found a cost-effective way to produce good yields of high-quality tomatoes in the early and late periods of the tomato season, when prices are at their peak. And, by being in the marketplace in the early part of the season, he is able to continue selling tomatoes from the field.

However, Steve cautions growers who are considering a purchase of this kind to do their homework. If winter production is one of your goals, choose another structure. If you have a particularly windy site, consider a different structure. But if you are looking for a three-season structure that is tractor-accessible and relatively inexpensive, the Haygrove may be a good choice for your farm.

Case Study: Intervale Community Farm

Member-owned Intervale Community Farm (ICF) is located in the heart of Burlington, Vermont, on the site of the city's last dairy farm. It was started in 1990 as a not-for-profit Community Supported Agriculture (CSA), and currently has nearly 500 members. Andy Jones has been the farm's manager since 1994. Andy, assistant farmer Becky Maden, and a staff of seven seasonal employees produce 20 acres of vegetables, flowers, and berries for member households. The farm is one of the oldest CSAs in Vermont, and is the single largest.

The Intervale is a 1,500-acre flood-plain delta at the mouth of the Winooski River, and is home to twelve other small farms, creating what Andy describes as a "collegial and supportive community of farmers and entrepreneurs." The farm sits on a level, well-drained soil that is suited to vegetable production. Although the weather at the Intervale is slightly moderated by Lake Champlain, the growing season is still relatively short. It is considered a cold Zone 5 or a warm Zone 4, with the average last frost on May 12, and first fall frost on October 1.

The farm's produce is distributed for about 22 weeks, from mid-June to early November. Members visit the farm each week during that period to pick up their shares and harvest their own flowers, herbs, peas, beans, berries, and cherry tomatoes. The weekly share includes baby salad greens, carrots, broccoli, cucumbers, and tomatoes, among other vegetables.

Andy says that the field-grown tomato season lasts five to six weeks—from early August through mid-September. Because member surveys indicated that tomatoes are favorite crops, Andy started using high tunnels in 1999 to ensure a steady supply of tomatoes to his shareholders.

ICF has a total of six tomato tunnels. Four are 14' x 96' units. Two measure 14' x 144', and have sides that are about 18 inches higher than in the other four. The gothic-shaped structures were made by Ledgewood Greenhouses in New Hampshire. Andy selected the structure for its strength, snow-shedding design, and economical cost, which was about $0.90 per square foot.

The frame cost between $1,200 and $1,250, not including the roll-up sides. The taller sidewalls added a couple hundred dollars to the purchase price but are well worth the price. In 2003, the four-year, six-mil greenhouse plastic that Andy uses costs about $350 for a 28' x 100' piece. The total cost of the high tunnel, including structural steel, wood for end-walls and sideboards, hardware, and the labor to construct it, was approximately $2,000 for a 14' x 96' house. Andy calculates a yearly cost of $400 to own the 14' x 96' structure, basing this figure on a ten-year payback. However, the metal tubing of the frames should last much longer. Andy estimates that the wood parts of the structure (hip boards, baseboards, and end walls) need replacing every 10 years.

Andy seeks a nice mid-size (7 to 10 ounce) red tomato for the bulk of the production. For the taller tunnels, which are trellised overhead, ICF has been using the 'Buffalo' variety and is currently trialing replacement greenhouse cultivars that are as flavorful and productive. In the shorter tunnels, where the tomatoes are trellised with a basket weave method, the main red tomato has been 'Jetstar.' This cultivar has a beautiful appearance, moderate size, and good flavor. 'Jetstar' is less resistant to *Fulvia*, though, so Andy continues to look for others. 'Big Beef' is a pretty good choice, but runs a bit larger than Andy likes for the CSA. Andy's trials of 'Fabulous' from Seedway looked favorable, though the fruit are not quite as tasty as 'Big Beef' or 'Jetstar.'

Some other types of tomatoes—heirlooms and other colors—are also grown at the farm, but these tomatoes represent no more than one-quarter of the total. Popular heirlooms are 'Cherokee Purple' and 'Rose d'Berne' which is pink. Every year a few new yellow and orange cultivars are tried, but the perfect combo of size, yield, and flavor is still elusive.

Andy sows his first tomato seeds during the first week of March. He seeds into row trays, and then, about two weeks later, pots into 4" square cells. The first tomato transplants are set out on May 1, about eight weeks after seeding.

Each tunnel has four beds. Tomatoes are planted in rows 42" on center, except for the two inner rows, which are just 34 to 36" apart since both rows are trellised overhead to the ridgepole. For winter greens production, they divide each tunnel into two outer beds 30" wide and two inside beds 36" wide, with three one-foot wide aisles.

The beds are usually rototilled in the spring, although when the residue is not heavy, they may be hoed instead. They add two to three cubic yards of compost per tunnel (roughly 65 cubic yards per acre) and other soil amendments as indicated by soil test results.

In addition to the compost, they generally apply 50 lbs. of greensand, a little over 20 lbs. of azomite and, for

calcium, about 25 lbs. of gypsum. Often they spread a little nitrogen starter fertilizer at a rate equivalent to 30 lbs. N per acre to give the early May planting a boost. Lately, they have been using a dehydrated chicken manure called *Cheap Cheap* from North Country Organics as their early nitrogen source. With a 4-3-3 analysis, this product provides a bit of soluble phosphorus and potassium as well.

The beds are covered with black landscape fabric, each outfitted with a single drip irrigation line. The same fabric has been in use for seven growing seasons and appears to be going strong. A 15' x 100' piece costs about $100.

X-shaped holes cut about 4" x 4" in the landscape fabric allow for easy transplanting. He has also tried cutting longer slits, but the strands of fabric tend to impede rapid planting as they pull free in later years. While burning makes tidy holes, Andy does not like burning plastic, and he and his crew found the razor-sharp edges of the torch-made transplant holes to be abrasive and objectionable. He said, "250 holes per house, 6 houses a year, 10 years per sheet of fabric…you get the idea."

Andy transplants one row of tomatoes down the center of each bed, using a 18" in-row spacing. This gives a plant population of about 250 plants per 14' x 96' tunnel.

Tomato irrigation is primarily accomplished with 0.6 gal/hr drip line. At transplanting, they typically soak the tunnel with an overnight watering. After that, the plants automatically receive about 25 to 30 minutes of water per day. A battery-powered timer ($35 from the local hardware store) controls the watering so no one has to remember to water. Once the fruit begins to ripen, they reduce watering to around 15 minutes a day. By mid September, they generally stop watering the tomatoes altogether.

Andy now uses determinate varieties in the shorter tunnels so that their vines don't overrun the structure. He uses a stake-and-weave system, where a stake is placed between every other tomato plant in the row. Andy finds that the effort of staking and stringing is rewarded by an increase in the proportion of marketable fruit and by easier harvesting. He prunes his tomatoes, removing all the suckers and leaving one leaf spur below the first flower cluster.

In the taller houses Andy uses an overhead trellis, prunes each plant to a single leader, and uses clips to hold the tomato vine to the trellis. Andy recommends taller structures because they offer more choices with respect to variety selection and because they give better air circulation. The additional air volume also helps to keep temperatures up in cooler spring and winter conditions.

Andy's planting schedule reflects his desire to extend his outdoor field production. Each year, about half the tunnels are planted early (from the end of April to early May). These are intended for the first four weeks of the harvest season. These tunnels have back-up heating units that are only used during very cold nights. The other houses are planted in mid-to-late June, and are harvested beginning at the end of August and continuing through the end of September. In between those picking windows are the field tomatoes, if the weather cooperates.

The tunnels have helped reduce insect pest and disease incidence in Andy's tomatoes. Insects in the tunnels have not been a problem, despite the absence of any kind of rotation. Diseases that were chronic problems in the field, such as the leaf blights caused by *Septoria* and *Alternaria*, are no longer a concern. An exception, however, is leaf mold, caused by the pathogen, *Fulvia fulvum.* This disease is particularly problematic where temperatures and relative humidity inside the tunnel have been high, chiefly in the late summer and autumn. Basket weaving, though beneficial in many ways, inhibits air circulation and field cultivars that are most suitable for basket weaving don't have the *Fulvia* resistance that some of the greenhouse varieties have.

The tunnels are ventilated by means of roll-up sides. There are no gable end vents and the tunnels' 8' x 4' doors (on one or both ends) are not deliberately used to manage air movement. The chief management activity associated with the tunnels is the time required for temperature and ventilation management. Andy estimates that during the "high maintenance phase," about a half an hour per day is dedicated to environmental management for the six-house complex. Spring tomatoes are pollinated with Class 'C' bumblebee hives. Late crop tomatoes rely on wind through the rollup sides to set fruit.

Andy has been very pleased with his yields. His six tunnels, along with about 800 field tomato plants on a quarter acre, are enough to provide each of his 500 members with 30 to 40 pounds of tomatoes over a period of eight to ten weeks. Harvest begins in earnest in mid-July, and winds down in late September, in time to plant a crop of fall salad greens. Andy estimates the cash value of the tomato crop at around $30,000 (17,500 pounds at $1.75 per pound).

Years of ICF member surveys have shown that tomatoes are always within the top five most popular crops and contribute one of the largest percentages to the overall CSA share value. Therefore it has made sense to invest in high tunnels to ensure success. Andy thinks the tunnels

might also be suited to trellised cucumbers and red peppers, but he has settled on tomatoes because they are the crop most valued by his members.

"With high tunnels, our members are pleased because we can provide them with more and better tomatoes over a longer period of time," said Andy. "And we are pleased because content members are likely to renew their memberships. Our financial stability stems from repeat business—it's far easier to make happy customers than to find new ones."

To increase the return on his investment in high tunnels, Andy has begun using them to grow cold-hardy greens offered as part of a winter CSA share. This share also includes stored squashes, cabbage, and root crops from ICF, supplemented with products from other local farms, such as organic eggs, goat cheese, and apples.

The kales, mustards, Tatsoi, Mizuna, arugula, and spinach are on Andy's short-list of hardy greens. Though ICF has experimented with other hardy greens such as Claytonia, Sylvetta arugula, Mache, and so forth, so far the standard field salad greens have outperformed them for ICF.

To prepare for the winter shares, Andy removes the tomato vines, twine, stakes, and plastic mulch by the end of September. In his experience, a winter salad crop must be direct-seeded in early October to be successful. Crop growth will be slow during the late fall because of the cooler temperatures and shorter day length. In unheated and unlit structures, most crop growth must occur before the end of November. After that period until the day length begins increasing again, Andy says, development virtually stops, except during particularly sunny days, and the crop temporarily enters a kind of suspended animation.

Andy's goal is to have a succession of salad greens harvests throughout the winter. Nevertheless, a single planting date is sufficient. The high tunnel is essentially a winter warehouse of salad greens. Once established, they will be available for harvest throughout the winter, as long as they are not exposed to extreme cold.

To help reduce the risk of freezing injury, Andy covers the crop with a medium-weight row cover that he suspends over low wire hoops. In his experience, the greens he grows are hardy down to about 21°F. So far, Andy has not felt the need to add supplemental heat. Nighttime temperatures inside the tunnel are generally 5 to 10°F warmer than outside temperatures, and the covers add another 5 to 10°F of warmth. As heat radiates from the soil, it is trapped under the low cover, offering protection to the plant canopy.

Andy direct-seeds his salad greens with a single row Planet Junior seeder. He had previously used a six-row pinpoint seeder for all these crops except for spinach. He counts on just one harvest, but sometimes a second cutting may be made in the early spring. By mid-February, when daylight exceeds ten hours, the crop shows signs of renewed growth. The mustard family crops do reasonably well through much of December, except for the kales which can thrive throughout the winter. Spinach is the mid-winter standout, and ICF is considering quitting all other green crops intended for harvest January or later.

To water their high tunnel greens, they set up Netafim DAN microsprinklers (these sprinklers don't put out much water) and soak the houses for 24 to 48 hours prior to planting. After that, they water overnight about once a week until later fall. The lack of irrigation water during winter months is a problem at ICF with its very sandy soil. Andy imagines that February and March yields would be greater if irrigation were possible. Given the opportunity, he supposes they would water once every three or four weeks during the winter.

Andy has also used the farm's heated 30' x 96' greenhouse for winter greens production. Even without supplemental heat, he saw significantly better greens growth in the greenhouse than the high tunnels. Andy suspects that the larger thermal mass afforded by the greenhouse structure provides a more consistent growing environment than the much narrower hoop house frames. This suspicion is reinforced by the fact that the taller hoop houses do better in the winter than the shorter versions.

The value of convenient mid-winter ventilation also has become apparent to Andy. He is currently examining the feasibility and cost of adding a small exhaust fan and louver to each hoop house for winter use. Last winter, which was warmer than usual, ICF had some disease problems in spinach that were largely a result of warmer, humid conditions. Andy has found the roll-up sides to be somewhat impractical for winter use, when a tight seal is often desired shortly after venting.

Enterprise Budget for a Six-Month Tomato Crop in a 2,000 sq-ft High Tunnel at the Interval Community Farm

Fixed Costs

Construction Costs	**Materials**	**Labor**
Site prep (tractor time, labor)	$60	$48
High tunnel layout	$10	$48
Frame & construction	$5,000	$576
Lumber, hardware, and labor	$800	$384
Endwall finishing	$250	$144
Water service	$50	$12
Irrigation (valve, tape, water timer, header, fittings)	$100	$32
Backup heater	$225	
Other -- weed mat	$200	
Other -- harvest containers	$200	
Subtotals	**$6,895**	**$1,244**
Total Construction Costs		**$8,139**
Fixed Costs		
High tunnel construction (divided by 15 years)		$543
Interest (construction financed at 7% for 15 years)		$285
Taxes, land, office expenses, fees		$800
Total Fixed Costs		**$1,627**
Total Fixed Costs (six-month tomato crop)		**$814**

Variable Costs (six-month tomato crop)

Materials and Machinery	
Plants	$700
Fertilizer and compost	$175
Irrigation supplies	$10
Stakes, string, clips	$200
Heater fuel	$75
Bees for pollination	$100
Poly covering (divided by 4 years)	$200
Misc. supplies, repairs, maintenance	$150
Subtotal	**$1,610**
Labor Costs ($12/hr)	
Bed preparation and fertilization	$144
Transplanting, laying drip tape and weed mat	$144
Site mowing and weeding	$144
Pruning & trellising	$576
Harvesting, grading, packing	$480
High tunnel clean-up	$120
Annual maintenance	$96
Environmental management	$360
Subtotal	**$2,064**
Total Variable Costs	**$3,674**
Total Costs	**$4,488**
Revenues*	**$8,750**
Net Returns	**$4,262**

*Revenues are based on a tomato yield of 3,500 lb per 14 X 144' high tunnel. The tomatoes are assigned a value of $2.50/lb, and revenues were $8,750.

Case Study: Star Light Gardens

Almost half an acre of intensive production in five high tunnels (17,500 square feet) complements an acre of field grown salad crops and other vegetables at Star Light Gardens, located one half hour south of Hartford, Connecticut. Mixed baby greens, mesclun, and tomatoes as well as arugula, basil, and pea tendrils are currently David and Ty Zemelsky's main tunnel crops. Close to year round sales of freshly harvested produce from this micro-farm provide the couple with their livelihood. Each had another career before they made a quick transition to farming in the late 1990s.

David always had a passion for gardening. In the years before he and Ty started their own farm, David deepened his horticultural know-how by lending a hand to an aging friend and long-time organic farmer. At the time, he did not imagine that pursuing his avocation would enable him to quit his day job.

Listening to his friend's tales of winter growing pioneer Eliot Coleman prompted the Zemelskys to make a 500 mile round trip pilgrimage to Coleman's Four Season Farm on Maine's Penobscot peninsula in October 1999. Ty said, "We didn't even know what questions to ask." They bought Coleman's *Winter Harvest Manual* and Ty, who describes herself at the "instigator," decided that there was no reason they couldn't start their own business using this model.

With their children grown, the Zemelskys had been exploring ways to be self-employed together. They were about 50 years old and fit enough to be running marathons. They wanted to find "good honest work" that was compatible with their values and provided a reasonable livelihood. A home-based enterprise was attractive to Ty who, as a visual artist, found working alone in her studio to be too isolating.

To build their first high tunnels, they took out a home equity loan. By Thanksgiving of that year, their son (a landscaper) had prepared the site and they had erected their first two high tunnels. They remember the date—April 9, 2000—of their very first greens harvest, from seeds sown in February. When June rolled around, with a small field planted outside and restaurants buying their produce, David left his school psychologist job for good.

Within two years, David and Ty had put up a total of four 30' x 96' high tunnels on a North-South axis. Next, they hired the local greenhouse fabricator to construct a 30' x 144' structure on an East-West axis, making it their warmest and brightest tunnel. All are gothic style.

Their first two high tunnels are skinned with double layers of plastic inflated with a small blower fan. Initially none of the tunnels had heat. After a few years, they decided to install a forced air oil furnace in one of these original tunnels to facilitate early tomato production. Ducts transport hot air to an adjacent tunnel. They have no inclination, however, to put heat in their other three tunnels.

The Zemelskys chose high tunnel design options that maximize passive ventilation. They set 30" roll up sides about 2' above ground level to protect young plants from cold blasts of air. Directly below the roll-up is the high tunnel baseboard. Plastic film covering the tunnel below the baseboard is buried in a trough in the ground. On each high tunnel, both gable ends have large doors that fully open. Under cold winter conditions, these passive venting systems are not feasible. David and Ty say they would have opted for ridge vents if they were more affordable.

In their first four tunnels, the Zemelskys experimented with two types of fans. Above the doors, each of these tunnels has a louvered vent on one gable end and a big exhaust fan mounted at the other. A thermostat triggers the louvers to open and let fresh air in. This automatically turns on the fan. They set the thermostat at 80°F for winter greens.

Horizontal airflow (HAF) fans are the second type they had installed. This conventional greenhouse ventilation system is comprised of four window fans hung from the trusses, with one pair blowing air up one side and the other pair blowing it down the other side. Their purpose is to keep air circulating inside, particularly on cloudy winter days when the tunnels are closed. After the Zemelskys stopped growing fall and winter lettuce (their mildew-prone crop), they eagerly stopped running these fans and significantly cut their high electrical consumption.

Ingredients of the Zemelskys' salad mix changes with the seasons and every year they experiment with new varieties. Their hardier, sturdier winter mix contains about eight different kinds of cold-hardy brassicas (including 'Siberian' and 'Dino' kale), and various Asian greens such as Tatsoi and Mizuna. Claytonia—which thrives in cold, low light conditions—is a winter favorite. Arugula accounts for as much as 30% of their sales. Pea tendrils are another important cool weather crop. Some of their seed comes from High Mowing, a small Vermont seed house that only sells open-pollinated, organic seeds. Wild Garden Seed in Philomath, Oregon is the source for chervil and mixed mustards they like called, 'Morton's

Mild Mustard Mix.' Johnny's Selected Seeds is another source.

Timing is very important for winter production since the growth rate of crops decreases to almost a standstill in the weeks leading up to winter solstice. To work around this cycle, the Zemelskys have learned to sow greens from early September through October 7 for winter harvest in their location. They start slower growing crops like spinach, chard, and beet greens earliest. For spring harvest, they have planted late into November and in February. With the exception of tomatoes, all of their high tunnel crops are direct seeded.

Intensive production and double or triple cropping requires ample nutrient availability. Before fall planting, David applies an inch of a purchased certified organic leaf-based compost. In the spring, he adds more compost as well as some organic fertilizer into the tomato transplant holes. The Zemselskys also make their own compost by windrowing leaves from local landscapers. Since these composts are low in nitrogen, David supplements them with a purchased fertilizer product from North Country Organics and alfalfa meal for extra nitrogen content. They test the soil periodically as required by their organic certification agency.

David used to roto-till the soil but he has discontinued that practice because he feels it damages soil structure and brings up weed seeds. Instead, he uses shallow tillage to prepare the planting beds. He is experimenting with a small power harrow, a tool that does not invert the soil. Alternatively, he uses hand tools for soil preparation: a saddle hoe to remove debris and old plants, a wheel hoe with a cultivator attachment, and a broad fork. Before planting, he rakes the seedbed and firms up the top layer of soil with a mesh roller.

Over the years, the Zemelskys have found weeds to be quite challenging. Weeds slow harvest and compete with the crops. Certain tenacious cool season weeds, like chickweed, have been very difficult to overcome. Stale seed bedding followed by flaming is proving to be the best prevention for weed proliferation. After preparing the seedbed, David irrigates and, when the weeds emerge, he cooks them with a propane backpack flamer. David is learning to leave two weeks between getting the beds ready and planting the crop to allow time for this technique.

After using a four-row pinpoint seeder for several years, David graduated to a newer six-row model that has built-in rollers. He said the six-row seeder is an improved model that is more forgiving than the four-row one. He recommends a plastic cover over the seed trays for keeping soil from kicking into each bin, and Johnny's incorporated that suggestion. He said, "At first it didn't seed well, but the company got the kinks out of it, for the most part."

With any of the pinpoint seeders, monitoring the operation of the seeder is critical in David's experience. He makes sure the shaft is turning and the belt has not jumped onto a different pulley as this determines how much seed is sown.

To achieve the intensive production he aims for, David prefers to grow his greens in blocks rather than rows. Rows allow for cultivation with a hoe, whereas blocks do not. He explained that seeding in blocks requires successful implementation of stale seed bedding to reduce the weed seed bank. If an area is too weedy, he can still use his six-row pinpoint seeder, filling only two of the six hoppers in order to skip two rows for every row he seeds.

Like others with a similar mix of crops, the Zemelskys use two different watering methods. For their summer crops like tomatoes and peppers, drip irrigation helps conserve their extremely limited water supply. With the aid of electronic timers, they irrigate three times a day—in the middle of the night and early morning hours—in order to load up the soil with water before it gets too hot.

With their greens seeded in blocks rather than rows, drip irrigation is not feasible. David is slowly converting his overhead irrigation to a product called "Ein Doers" that is sold by various dealers. Four rows cover a 30' wide tunnel. He also uses a conventional rotating sprinkler, mounted on a tripod, and another conventional sprinkler that goes back and forth.

After sowing, the late plantings are protected with a medium-weight, spun polyester row cover to assist the crop in germination. This microclimate warms the soil 2 to 3°F. Sometimes their plantings under the row cover experience some dieback. When the seedlings reach a certain size, the row cover is suspended over wire hoops pressed into the ground. The hoops prevent the row cover from chafing the fragile leaves and freezing onto the plants. This structure also keeps condensation off the plants.

The Zemelskys begin their high tunnel greens harvest in November and December. For the first few years, they harvested throughout the winter without a break. They have since stopped selling greens in January. By winter solstice, short day length and low light have considerably reduced plant growth, so they take a needed break while they wait for more re-growth to occur. By early February, with the sun higher in the sky and the light intensifying, they resume harvesting and also reseed some beds as necessary to ensure a strong March and April harvest.

Harvesting salad mixes constitutes a major portion of their labor. The dense, good quality crops at Star Light Gardens can be cut with more speed and the Zemelskys can cut almost 30 pounds per hour, compared to 20 pounds an hour in a more average stand. Ty used to be the main cutter but an old back injury was aggravated by all the bending. Now David does most of the harvesting, with the aid of a harvest cutter and a net bag in a laundry basket.

For the greens harvest, they cut with good, small, light-weight kitchen knives into nylon nets (from a fishing supply company) placed in laundry baskets. They wash the greens in the net bags and then run the bag through the spin cycle of a standard washing machine. They mix the greens to their standards or for special orders in a home-made mixer. If a batch of salad mix grows too big, they sell it as braising mix.

A couple of winters ago, the Zemelskys ceased trying to grow lettuce in the winter. David says that lettuces are too susceptible to powdery mildew under low light and high humidity conditions to be worth the trouble of growing in winter. They also grow too slowly after their August planting, requiring a full week longer than Brassicas, and are not nearly as cold hardy. Since Ty and David market their produce as local and seasonal, their customers readily accepted their explanation, without "batting an eye." Always experimenting, they may try seeding lettuce in February for the spring harvest.

In 2006, a visit to Bryan O'Hara's low tunnels in eastern Connecticut sparked a fundamental change in Star Light Gardens' cropping philosophy. *(See section on Low Tunnels, page 38.)* In mid- and late September that year, David planted lettuce outside in low tunnels. He says his goal is to have enough field-grown lettuce to supply their markets through Thanksgiving, and then start harvesting in the high tunnels. The system appears to be working, though he will need to tinker with crop timing in both of these growing environments.

Pea tendrils are a money-making crop that the Zemelskys grow wherever they can fit it in, such as around the colder edges of their high tunnels and between the rows of tomato plants until they fill out. While pea plants cannot handle freezing the way hardy Brassicas and Claytonia can, they do well in cool fall and late winter conditions.

A pound of 'Dwarf Grey Sugar Pea' seed costs $1.30 and yields about five pounds of tendrils on 5" high pea plants. The Zemelskys plant 10 to 15 pounds of seed per week. David and Ty sell the pea tendrils alone for $13 a pound. Occasionally they add them to salad mix for more weight. David says, "Pea tendril pesto has regular basil pesto beat, and so much earlier!"

They have also added micro-greens to their marketing mix. They have found that these greens have already helped their bottom line.

Depending upon how early their field dries out, they transition to harvesting field-grown greens sometime in April or early May. The transition between high tunnel and field production can be a challenge. They have attempted to overwinter field greens in low tunnels, but the results have not been consistent.

Initially the Zemelskys only produced salad greens in the tunnels, leaving them vacant in the summer. In their fourth year, they added tomatoes and basil. Tomato transplants go into the high tunnels from March until early April and the tomato harvest lasts from June through early October. They must quickly pull out the tomato plants in time to reseed the tunnels to fall greens.

The Zemelskys make a wire trellis for the tomatoes using the support structure of the high tunnel. They typically use double leaders, pruning each plant to two main stems. The rows run the length of the tunnels, with nine rows fitting their 30' width, though David is considering growing fewer rows. In order to get earlier tomatoes, they may heat one tunnel to 60°F. This year, they began experimenting with grafting tomatoes. They specialize in heirloom varieties for their discerning customers and also grow some indeterminate greenhouse cultivars. Chefs order tomatoes by color.

Star Light Gardens has been very successful in marketing. Restaurants were originally the mainstay of their sales, but after several years of farming, they added farmers' markets and the Yale University Sustainable Dining Program to their customer base.

Connecticut has few farmers in relation to its population, and organic, fresh, and unique produce is in great demand. The Zemelskys consciously aim to differentiate their produce from generic products, and they trial new varieties every year. They have been able to maintain their wholesale price for salad mix at $8 per pound. David said, "There is no competing product. What you get from California does not compare with what we have."

The Zemelskys enjoy a nice relationship with chefs and find it advantageous at their scale not to rely on a distributor or purveyor. They get new accounts by visiting restaurants or when chefs find them through the Northeast Organic Farming Association of Connecticut (NOFA-CT). "Chefs are movable people," said David, "We can gain or lose accounts when they change jobs."

Currently they wholesale to about two dozen restaurants. Their weekly delivery route also includes four

stores (including a family-owned IGA and natural foods stores).

They first tried selling at a farmers' market in 2004, when the founder and manager of a new market in New Haven recruited them. A couple of years later, they joined another farmers' market an hour away, which began when the sponsoring organization of the first market expanded its reach. Farmers' markets have been lucrative and sociable for the Zemelskys, and have also resulted in contacts with chefs and other buyers.

The Zemelskys have also been selling a significant amount of their production to Yale University since 2004 when it began piloting local food in one dining hall. The University is willing to pay 50% more than the going rate to obtain locally grown, preferably organic, food. Yale buys a third to a half of their salad greens during the late fall and early winter.

Enterprise Budget for a Six-Month Brassica Greens Crop in an Unheated 3,000 sq-ft High Tunnel at Starlight Gardens

Fixed Costs

Construction Costs	**Materials**	**Labor**
Site preparation, bulldozer		$1,500
High tunnel construction		$600
High tunnel frame	$3,000	
Lumber and hardware	$400	
Endwall finishing		
Water and electrical service	$311	$100
Irrigation	$150	
Exhaust fan and louvered vent	$750	
Bed preparation	$150	
Other (horizontal air flow fans)	$330	
Subtotals	**$5,091**	**$2,200**
Total Construction Costs		**$7,291**

Fixed Costs	
High tunnel construction (divided by 15 years)	$486
Interest (construction financed at 7% for 15 years)	$255
Taxes, land, office expenses, fees	$225
Total Fixed Costs	**$966**
Total Fixed Costs (six-month winter season)	**$483**

Variable Costs (six-month winter season)

Materials and Machinery	**Cost**
Seeds	$46
Fertilizer, lime and compost	$78
Plastic mulch and row cover	$75
Heater fuel and electricity	$25
Beneficials and pesticides	$10
High tunnel poly cover (1/2 year)	$110
Delivery costs	$175
Subtotal	**$519**

Labor Costs ($20/hr)	
Poly cover installation and removal	$75
Bed preparation and fertilization	$160
Planting	$60
Irrigating and managing row cover	$20
Harvesting	$750
Washing and packing	$300
Sales and delivery	$420
Subtotal	**$1,785**
Total Variable Costs	**$2,304**
Total Costs	**$2,787**
Revenues*	**$6,000**
Net Returns	**$3,213**

*Revenues are based on a Brassica greens yield of 0.25 lb/sq-ft or a total of 750 lb per cutting in the Zemelsky's 3000 sq-ft high tunnel. The greens were sold at $8/lb. Arugula, which sells for $11/lb and is not as cold resistant as some other brassicas, was not included in this accounting.

Case Study: Slack Hollow Farm

Twenty-five years ago, Seth Jacobs and Martha Johnson started Slack Hollow Farm in the Taconic foothills in Argyle, New York, located a little over an hour Northeast of Albany. In their early years, they did all their fieldwork with horses and depended heavily on hand tools. Today, with 15 acres in vegetable production, the farm claims three small tractors, numerous implements, a box truck, a greenhouse, and two high tunnels. Seth and Martha grow a wide range of vegetables and salad greens that they sell at two substantial producer-only farmers' markets and to wholesale accounts. Their primary high tunnel crops are spinach and other salad greens, produced in the late fall through spring, and tomatoes and basil, grown in the warmer months.

The first of their two tunnels is a 21' x 120' gothic-shaped structure manufactured by Ledgewood Greenhouses. They built it in 1995 from a kit and estimate that it cost between $6,000 and $8,000. This relatively simple tunnel does not have electricity, heat, or fans, and uses roll-up sides for ventilation. It has an East-West orientation. In this structure, they utilize a two-crop rotation. They grow tomatoes and basil from early May through late September or early October, and spinach from mid-October through early April.

Seth and Martha stopped growing tomatoes in the field about ten years ago because the yield and quality of their tunnel-raised tomatoes is so much better. Their farm in Argyle is in Zone 4, providing relatively little time to for a field-raised crop to develop. Also disease pressure in field-grown tomatoes is high, reducing marketable yields and profitability.

Seth and Martha have been growing spinach during the winter for four years and the system they have developed works well for them.

As a certified organic farm, compost has been the basis of Slack Hollow Farm's fertility program. In the past, they added farm-made manure-based compost at the rate of 10 tons per acre by running their manure spreader down the middle of the tunnel. New organic regulations require long intervals before harvest, so now they only apply compost in April, prior to planting the tomato crop. (A foliar spray of Epsom salts for magnesium on tomatoes is their only other nutrient input.)

After removing the tomato vines and trellises at the end of September, they roto-till the soil with a tractor-mounted tiller to prepare a good seedbed. Time permitting, they will flame-weed before seeding, but even when they can't get to it, weeds appear to be under control. Martha direct-seeds the spinach using a one-row Planet Junior seeder, producing remarkably straight rows. She aims for 12 to 16 seeds per foot, with rows four inches apart.

'Space' is the variety they prefer because of its leaf type, eating qualities, yield, and cold-hardiness. Spinach is very winter-hardy. "No temperature can kill it," Seth says.

Protecting the spinach plants with floating row cover is essential. They use up to four layers of mid-weight spun polyester row cover to buffer the crop from sub zero temperatures. The aim is to manage the freezing of the crop and soil during very cold periods, as this would interfere with or prevent harvest.

In the unheated tunnel, they get at least three harvests of spinach during the winter, taking cuttings on a given section about 60 days apart, depending on the amount and length of sunshine and the temperature. For plants harvested on December 20, the shortest day of the year, a second harvest will be ready during the last week of February. Production all but ceases between December 20 and January 30, so spinach is stockpiled for that period. A bed cut at the end of February will be ready for another cutting in early April. At this point, they take their last harvest, so they can renovate the tunnel in preparation for tomato planting.

They cut most of the spinach plant, leaving one or two new leaves behind, harvesting by holding the prostrate leaves up with one hand, and cutting with the other.

The first cutting of the winter spinach is of the highest quality, and the sugar levels seem to be higher. Customers notice that it is sweeter than outdoor in season. Leaf quality goes down with each cutting, but the taste remains unsurpassed. And it is still superior to what is found in grocery stores at that time of year.

Their markets for winter spinach and other greens include a large food co-op in Albany, with which they have had a very long relationship, and a large farmers' market that operates throughout the winter. If they expand their winter production, they would add more markets, or perhaps start a winter CSA. Currently, retail spinach prices are in the range of $10 to 12 per pound. They expect to harvest a total of 1,000 to 1,500 pounds of spinach from the unheated 21' x 120' tunnel, generating sales of $10,000 to $15,000 during the winter.

In 2004, Seth and Martha constructed a second high tunnel which some might consider more a soil-based

greenhouse. Its North-South orientation was determined by their existing field layout. The 30' x 120' gothic-shaped structure was made by Rimol, a company that provides valuable technical assistance. Unlike their first high tunnel, they had this one built by professional contractors. It cost about $25,000 to build, including the structural steel, the heating and venting systems, cover materials, and labor.

For ventilation, they outfitted the structure with thermostatically controlled automatic roll-up side curtains and gable-end vents. These features cost only a few hundred dollars more than a big exhaust fan and there is no power bill. Four standard greenhouse fans improve interior air circulation during warm weather and for fall germination. Access is provided by large tractor doors and, in winter, by a small people door that opens inward so snow shoveling or plowing is not required.

They covered the structure with a single layer of plastic. On the end-walls and roll-ups they used a woven poly with 90% light transmission which is much more durable and long-lasting than normal greenhouse film. They opted for extra-heavy bows spaced 5' on center, rather than the standard 4' spacing because the cost was lower. In-ground heat tubes circulate hot water to warm the soil and root zone.

Several other growers now produce spinach for winter farmers' markets in their area, and competition has increased. To take full advantage of their winter marketing opportunities and to more fully satisfy their customers, they decided to expand their crop mix to include a range of less hardy salad greens. Building a new structure has made this diversity more possible. Seth said, "We would like to increase production during a time of year when competition from other local producers is lower." They have been using their new tunnel to grow a variety of cold-hardy greens including arugula, Tatsoi, Mizuna, kale, radishes, turnips, beets, Swiss chard, and Bok Choy, as well as spinach. Some of these crops are seeded with a pinpoint seeder. Between the lateral beds (not raised) wooden boards focus foot traffic in very narrow paths. (They grow the tomato crop in rows running the long way.) They use the same production techniques here as in the unheated tunnel as well as the same general rotation. The addition of heat in this structure gives them more flexibility with planting dates.

This new heated high tunnel has benefited their spinach crop in several ways. While growing winter spinach in the original high tunnel, Seth and Martha found that they could not harvest early in the morning or during very cold days because the leaves would be frozen and quite wilted. The addition of a small amount of ground heat enables them to harvest spinach during these cold periods.

During a very high wind event in late February 2006, they lost the plastic on their older high tunnel. The plastic film on this house needed replacing and the pine hip boards had rotted, Seth noted. (Now all wooden parts in Slack Hollow Farm high tunnels are made of Eastern white cedar.) The loss of the plastic occurred right after they had finished the first cutting of their winter spinach. This crop was lost to cold burning.

At the same time, two beds of spinach planted around December 15 were maturing in the new, ground-heated tunnel. "We got astounding yields," said Seth. They cut these spinach beds on alternate weeks from the end of February until the last week in April and were able to supply their farmers' market from a much smaller planting. "Production far surpassed the unheated high tunnel," Seth said.

Even with the in-ground heating system, row cover remains an essential element of winter growing at Slack Hollow Farm. In the heated high tunnel, daily covering and uncovering with medium-weight floating row cover is required to prevent overheating during the day. To streamline the application and removal of the row cover, this winter they plan to construct a hand-cranked roll-across covering system within the high tunnel. *(See inner coverings section, page 52.)*

At Slack Hollow Farm, the decision to equip a new high tunnel with ground heat was intuitive. *(See heating section, page 49.)* Seth felt that for a tunnel covered with a single layer of poly, such a in-ground heating system would be significantly less expensive to run than heating the air.

Seth and Martha have always used a single layer of plastic because they believe it has a smaller environmental footprint or impact than two layers. *(For a different view, see Single vs. Double Layer in Selecting Your Structure section, page 31.)* It transmits more light, results in half as much plastic to dispose of, and averts the need for electricity to power an inflator blower. It is less resource-intensive to use lightweight row covers inside—which lasts for many years. Seth stressed that they do not use high tunnels to grow a warm weather crop out of season. They also do not use plastic mulch.

Seth estimates that a quarter to a third of the farm's revenues come from their two high tunnels. He expects that the new (more costly) tunnel will pay for itself within two to three years. It is very inexpensive to operate, requires no machinery except for tractor tillage twice a year, and takes only about 12 hours per week of labor, yet produces very high yields.

He anticipates $25 to $30 in sales per square foot.

Seth and Martha attribute much of their initial interest in winter production to their desire to offer year-round employment to their farm manager, Colleen Converse. She is, in turn, responsible for most of the winter harvesting and marketing.

"Our expansion into winter production has been employee-driven," Seth said. They are able to travel in the winter because the manager can handle the farm, and they can also cut back in summer by placing more emphasis on winter markets. And year-round high tunnel production has also evened out the farm's income.

Seth and Martha like tunnels so much that they actually have a third tunnel, 30' x 48', that they use as their washing and packing shed. With the wash station end covered with three layers of shade cloth in the warmer months, it is comfortable all summer, and far more pleasant than a dark barn. An added benefit is no property taxes as assessed on this temporary structure.

Enterprise Budget for Winter Spinach Crop in an Unheated 2,500 sq-ft High Tunnel at Slack Hollow Farm

Fixed Costs

Construction Costs	**Materials**	**Labor**
Site preparation, bulldozer		$1,000
High tunnel construction		$2,100
High tunnel frame	$5,000	
Lumber and hardware	$500	
Endwall finishing	$400	
Water service		$850
Irrigation	$700	
Bed preparation	$240	
Subtotals	**$6,840**	**$3,950**
Total Construction Costs		**$10,790**

Fixed Costs	
High tunnel construction (divided by 15 years)	$719
Interest (construction financed at 7% for 15 years)	$378
Taxes, land, office expenses, fees	$1,377
Total Fixed Costs	**$2,474**
Total Fixed Costs (six-month winter season)	**$1,237**

Variable Costs (six-month winter season)

Materials and Machinery	**Cost**
Seeds	$50
Compost	$200
Irrigation supplies	$50
Row Cover	$100
Poly covering (divided by 4 years)	$90
Packaging	$30
Delivery costs	$560
Subtotal	**$1,080**

Labor Costs	
Bed preparation and fertilization	$500
Seeding	$48
Irrigating	$100
Harvesting, grading, packing	$1,500
Sales and delivery	$1,500
High tunnel clean-up	$100
Subtotal	**$3,748**
Total Variable Costs	**$4,828**

Total Costs	**$6,065**
Revenues*	**$12,000**
Net Returns	**$5,935**

*Revenues are based on a spinach yield of 1,000 lb in a 21 X 120' high tunnel. The spinach was sold at $12/lb. Yields were reduced this season because a severe storm damaged the plastic cover. Revenues the previous year were $15,500 on yields of 1,550 lb and a selling price of $10/lb.

High Tunnels and Marketing

One of the primary reasons for adding high tunnels to a farm is to increase marketing opportunities. High tunnels enable growers to extend their marketing season. And because crops grown in high tunnels are usually of better quality, they usually command a higher price and attract quality-conscious shoppers.

Producing a crop in a high tunnel is typically more costly than growing it in the field, due to the structure's capital costs and increased manual labor requirements. On the other hand, when calculating the cost per pound or bunch produced, high tunnels often come out ahead. Depending upon the year and the crop, high tunnel yields tend to be significantly higher than those for field production. The more controlled environment favors production quantity and quality. And when outdoor yields are severely impacted by weather, pests, or other factors, the comparison can be particularly striking.

Since the investments in high tunnel crops are greater, it makes sense for farmers to maximize the returns on high tunnel crops through a deliberate choice of marketing strategies. Small farmers often find direct marketing to be essential, whether through farmers' markets, farm stands, Community Supported Agriculture (CSA), and even restaurant sales. Out-of-season production can pose significant challenges for marketing but it can also offer tremendous potential for creating a profitable niche.

Boosting Value

There are many ways to enhance the value of production. When direct marketing at farmers' markets or to chefs or small retailers, product diversity can enhance sales and put a farm in a preferred position. Since an individual customer will only use a finite amount of one product, a farmer can boost the food dollars spent by each buyer by offering more products. Most direct marketers raise a variety of crops during the growing season, and this can also be an effective strategy during the extended season.

For direct sellers, good signage, a friendly and positive demeanor, and attractive product presentation will probably be adequate for creating an effective image. Home-grown promotions that take a little time but cost little or nothing can also help create a buzz. Farmers can pitch their stories to the media with press releases or phone calls suggesting why they are of interest. Writing a newspaper column or getting a gig as a radio show guest will also increase public exposure. A public open house or tour for chefs are other means to make an impression on potential or current customers.

Packaging, labeling, websites, brochures, ads, or other forms of branding may play a role in adding value, depending on the market outlet. Any of these items may be helpful in the right situation. For example, a brochure is indispensable for CSA farmers like Andy Jones in recruiting members annually. Steve Groff belongs to a grower co-op selling tomatoes and other crops to supermarket chains. A life-size cut-out of Steve for display in the supermarkets helped create demand for the group's produce. As wholesalers with 50 acres of high-value crops in production, the Cramers can justify having a couple of websites where buyers can view their flowers and learn about the seed varieties they sell. For most small-scale growers, high expenditures on a lot of costly professional marketing materials are usually not warranted.

Farmers' Markets

With minimal investment, farmers' markets give farmers the opportunity to represent their farms and their products directly to the public. Good farmers' markets can be very competitive marketplaces; however, they also gather together far more shoppers for a compressed period of time than most individual farm stands. Successful farmers' market vendors develop relationships with their customers. They establish loyal followers who are not distracted by lower prices offered by other farmers at peak harvest.

The competition inherent in successful markets also speeds up the spread of appropriate innovations like high tunnel production methods. With shoppers comparing the various sellers, willingness to learn and flexibility to change are important attributes for farmers whose primary outlet is the farmers' market. Seth Jacobs has tried to position Slack Hollow Farm ahead of the curve. He was the first in his market to grow large quantities of spinach all winter in an unheated high tunnel. As other farmers adopted this practice, he anticipated the next opportunity by constructing a ground-heated tunnel to expand and diversify his winter production.

Taking Initiative to Extend the Farmers' Market Season

When farmers decide to use high tunnels to lengthen their harvest, they may not find a ready market awaiting them. For instance, farmers who rely on mid-season farmers' markets may have no outlet in early to mid- spring, late fall, or throughout the winter. Without a good market outlet, there is no point in extending the season.

Waiting for a market to appear is not practical. Instead, many farmers are

taking initiative to develop or strengthen markets to serve their needs. Farmers need not organize markets single-handedly. Some of the best farmers' markets are joint projects of the farmer members and community advocates or enthusiasts. Farmers generally do need to stay involved to ensure the market will continue to work for them.

One of the most promising strategies for farmers growing in the winter is starting an indoor winter farmers' market. With proper planning and publicity, these new markets are finding receptive audiences. Our region now boasts at least four weekly winter markets, all started between 2002 and 2006. Fresh spinach, brassicas, salad mix, and sometimes kale and chard are popular winter items, and unless there is a large producer in attendance, greens usually sell out early in the market day.

Some farmers' markets only run from mid-June through September. Such a short time frame is not conducive to the creative use of high tunnels. For regular farmers' markets to start earlier in the spring or continue later into the fall, farmers must have appealing foods and other products to sell at these times.

A farmers' market will not attract a critical mass of shoppers if spring greens are the only product for sale. Vegetable farmers who are extending the season might want to recruit farmers who sell meats, poultry, cheeses, and other animal products, as well as bakers and processed and prepared food makers to create diversity and interest at a market.

Pick-Your-Own

Under the right circumstances, fruit grown in high tunnels can be an ideal crop for a pick your own operation. Of the fruit with which we are familiar, fall raspberries and sweet cherries seem to be especially good candidates. The appropriateness of pick-your-own depends on a farm's location, the temperament of the farm operator and farm family, and the capacity of the farm to accommodate large numbers of customers and their vehicles. Another consideration is the timing of the harvest season for a particular type of fruit. Even when fully vented, the temperature in single bay high tunnels can become stifling in warm weather.

Ed Weaver has found the climate protection offered by his multi-bay high tunnels to be attractive to his pick-your-own fruit customers. The quality of his sweet cherries is much improved, and even in inclement weather, customers can come and harvest protected from the weather. Due to the potential for spreading disease, pickers need to stay out of plantings when leaves and fruit are wet, even though rain may have ceased. Because of these factors, high tunnels enhance his customer base.

Community Supported Agriculture (CSA)

Instead of increased profit, the most important benefit for the Community Supported Agriculture farmer's livelihood may be risk mitigation. A CSA farmer might not be able to isolate the actual economic return from a high tunnel since CSA members pay a lump sum for their share of the entire harvest.

CSA members agree to share the financial risks with the farmer when they purchase a share in advance. It is in the interest of the CSA farmer to minimize the production risks inherent in agriculture and deliver the vegetables the members expect. Otherwise members may become disgruntled and the future of the CSA may be jeopardized.

For example, CSA farmers in northern climates often use high tunnels to ensure an adequate and sustained tomato crop. The added warmth of a high tunnel may permit an earlier harvest, and will guarantee production even in a cold year. By avoiding precipitation and associated disease, high tunnels will often keep the crop going longer. In a rainy year, high tunnel tomatoes usually significantly outperform field tomatoes. All of Andy Jones' high tunnel production goes to his CSA members. Having a consistent, high quality tomato crop helps keep Andy's members happy and coming back year after year.

Starting the CSA harvest earlier in the season or extending it later into the fall can also be achieved with high tunnels. A longer season may well allow the farmer to command a higher price per share. A CSA farmer might also use high tunnels to increase the diversity of produce at the growing season's start, even in a wet, cold spring. All of these uses can help a CSA farm differentiate itself and attract a loyal membership.

Some farmers have organized winter CSAs using high tunnels to produce greens. Winter CSAs can be as simple or complex as the farmers wish. In Wisconsin, a farmer started a stand-alone spinach share. He delivered spinach every couple weeks to Madison customers over the course of the long cold winter.

In a more typical winter CSA, fresh salad ingredients like high tunnel-grown spinach, brassicas, and even lettuces complement storage vegetables like carrots, onions, beets, parsnips, rutabagas, and winter squashes. Winter CSAs tend to provide vegetables to their members less frequently than growing season CSAs. Biweekly or monthly deliveries from December through March are typical.

A winter CSA need not be very demanding of the farmer's time. Providing off-season cash flow may give winter CSAs value beyond the relatively low income they bring in. Another benefit of a winter CSA is

allowing the farmer to amortize the capital costs of the structure over multiple crops per year.

Some CSAs are collaborations among two or more farmers. Some CSA farmers are not interested in continuing production into the winter, but have the ability to grow sufficient storage crops to serve a CSA. A high tunnel farmer who grows greens during the winter could join forces with such a farmer. This sort of CSA partnership presents a direct sales opportunity for a high tunnel grower in areas where there are no winter farmers' markets.

Selling Directly to Restaurants and Specialty Stores

To gain acceptance with chefs and specialty stores, farmers find that interesting, superior tasting and exotic varieties are a real draw. Careful variety selection also "adds value," entitling the producer to higher prices. The Zemelskys have maintained strong prices for their tomatoes with an upscale chef clientele by growing heirloom tomato varieties. The fact that such varieties may be less productive, don't travel or store well, or may be more delicate makes them less attractive for many farmers, but these characteristics also open up a niche for small farmers who depend on direct marketing. Since these finicky crops are not easily mass marketed, they have not been embraced by supermarket chains or produce distributors. Specialty stores and independent restaurants can use these varieties to distinguish themselves from chains by offering these kinds of specialty vegetables.

Wholesaling

Effective wholesaling requires appropriate volumes of consistent products. The task of the wholesaler is finding customers who appreciate what they have to offer. In good wholesale situations, quality matters, and high tunnels can help guarantee the desired quality. Getting a jump on the season and providing reliable delivery and service are other attributes that create enduring relationships with wholesale customers. Early production gets Cramer's Posie Patch in the door with brokers who would otherwise look elsewhere for their suppliers. And the high quality flowers they grow in their tunnels help them keep their customers all season long.

Some buyers are interested in purchasing from farms in the region as a way to gain their own customers' loyalty. For instance, Hannaford, a Maine-based grocery chain, recently stepped up its locally grown program with the hope of attracting more farmer suppliers and capitalizing on their efforts with a customer campaign.

A group of Lancaster County growers, including Steve Groff, have developed a wholesaling relationship with a regional supermarket chain in Philadelphia and its suburbs. High tunnels gave the group an edge in dealing with this buyer. The Haygroves afford more consistent production and higher quality, two critical factors for supermarkets that are staking their future on excellence in their produce departments. In addition, the group is able to supply tomatoes beginning early in the spring, and extending late into the fall, long after field production in the region has been shut down by frost and disease pressure.

Site Considerations

It is a good idea to give careful consideration to where a high tunnel will be built. Success with the structure is highly dependent on its location. The high tunnel should be conveniently accessible, where water and electricity (if desired) can be supplied without excessive cost. A well-drained site is essential, and the site should be graded to divert water. The site should offer full sun and protection from the wind.

Check local zoning ordinances and permit requirements before you proceed. Under most local zoning ordinances, high tunnels are viewed as "temporary" structures that do not require a building permit. Similarly in most jurisdictions, high tunnels are not assessed as a property improvement and therefore are not taxed.

Utilities

Clean water that is free of sediment and chemical contamination must be reliably available in sufficient volume throughout the year—or at least during those months when plants will be growing. "Dirty" water may spread pathogens, blocks emitters in drip irrigation tape, and can even stain the high tunnel's poly covering.

Electricity is not a requirement for high tunnels as they are strictly defined. Most are covered with a single layer of plastic and therefore do not need an inflation fan to create the airspace between double layers of film. Similarly, passive ventilation is generally adequate. If you decide that electricity is desirable, site the high tunnels close enough for an economical connection with the electrical grid or consider using solar panels *(see "Photovoltaic Inflation Systems" on page 48).*

If use of a backup heating system is anticipated, the tunnel should be accessible to fuel delivery vehicles, and a fuel storage site should be identified.

Tunnel Access and Room for Expansion

High tunnels are relatively labor-intensive structures and require frequent access. In most situations, there is an advantage to locating high tunnels close to the farmhouse and established work patterns. Truck and tractor access is essential for moving product and supplies in and out. Proximity to the washing area, packing shed, and processing and distribution area will simplify the operation.

When considering where to locate your first high tunnel, keep in mind that you may want to add more tunnels in the future. As one grower put it, "High tunnels seem to like company." Make sure that your layout provides a logical plan for expansion, while also accommodating farm traffic and snow removal.

With his array of six 14' wide high tunnels, Andy Jones suggests placing tunnels as far apart as they are wide. Ted Blomgren suggests leaving alleyways that are at least as wide as the high tunnel is tall to prevent the shadow from one structure from falling on the adjacent structure.

Air Movement and Orientation

An ideal high tunnel site allows the free flow of air in summer and provides protection from cold wind in winter. For both passive and mechanical ventilation systems to be effective, the site should be open. Adequate ventilation will help remove hot air from the high tunnel. It will also remove excess moisture, reducing leaf wetness and foliar diseases. Creating favorable environmental conditions will result in healthier plants. Avoid cold pockets (i.e., the bottom of a hill) and areas of turbulence from adjacent hills or tree lines.

Good high tunnels are sturdier than they look. But a constant pounding and shaking from the wind can be hard on a structure (not to mention a farmer's nerves). Orienting the gable end to face the prevailing wind helps limit the structure's exposure. A windbreak is a good idea, especially for winter growing, as long as it doesn't affect sun exposure.

Water Movement and Drainage

High tunnels are most successful when they are built on well-drained sites. Removing excess water from around the high tunnel is absolutely necessary. Run-off from a high tunnel roof and from rain and melting snow can be significant. An inch of rain falling on a 30' x 96' house, for example, works out to be 0.6 gallons per square foot, or 1,728 gallons over the entire structure. This water and ground water should be diverted by a swale around the high tunnel. If there is uphill runoff, it is wise to divert this water before it reaches the high tunnel. Ideally, the tunnel should be at least a foot above grade of the land around it. A high tunnel water plan should be designed for the worst-case scenario of frozen ground with lots of rain.

In addition to surface water, subterranean water and seasonal springs must be avoided or dealt with. Ground water will wreck havoc on your crops, potentially causing devastating problems such as disease, secondary insect infestations, denitrification of the soil, and heat loss, among other problems.

Level and Square

High tunnels need not be on a level site. A little slope is okay, and a very gradual slope from one end to the other can actually be advantageous. This allows better flow when using low-pressure drip tape (with the headers and manifolds at the top), and offers the ability (if needed) to blend the high tunnel into the existing terrain without as much excavation. This slope also facilitates the addition of gutters if you want to collect or facilitate the removal of rainwater.

Too great a slope, however, can compromise the structural integrity of the high tunnel. Heavy snow loads that bear asymmetrically on a structure may cause its collapse. And your structure should be square. Kit greenhouses with pre-drilled holes for purlins, for example, will not align properly if the structure is out of square.

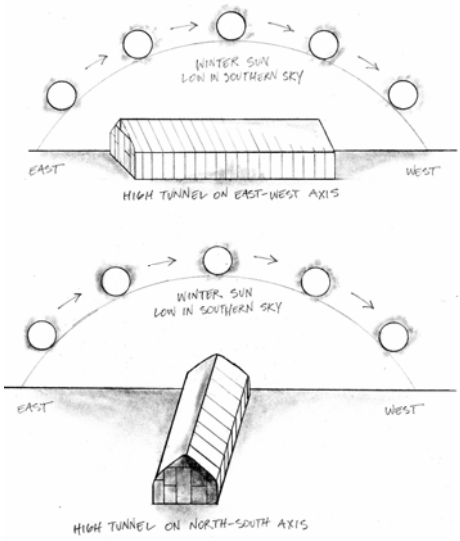
Exposure and Orientation

The site should be free from shade, as the first principle of high tunnel growing is ensuring full sun. Unless you are already attuned to the sun's movements, you'll be surprised to learn of the changes in its path across the sky over the course of a year. Hills, trees (even deciduous trees), and buildings can greatly restrict sunlight in the winter when sun is low on the horizon. Use a good sun chart such as the one in "The Passive Solar Energy Book" by Edward Mazria or at www.mysundial.ca/tsp/sun_charts.html.

Traditionally, greenhouses are oriented along a North-South axis to avoid shading. If you are certain that you will only be growing during the warmer months, this orientation will be acceptable. However, if you wish to maximize sunlight energy during the low light period of winter, it makes sense to orient high tunnels along an East-West axis. The Zemelskys, who grow year round in five high tunnels in Connecticut, found that their newest structure—the only one oriented East-West—outperformed their four others which are on a North-South axis.

When the sun arcs low across the southern sky during the winter months, solar radiation strikes the plastic of a North-South house at an oblique angle. When sunlight strikes at an oblique angle, some of the radiation is reflected outward and is lost. Solar gains in a high tunnel are greatest when solar radiation strikes the cover at a 90 degree angle.

During the winter and early spring, an East-West orientation improves this angle of incidence, more effectively capturing solar radiation. And a gothic-shaped structure captures this incoming radiation better than a Quonset structure except when the sun is high overhead, as it is during summer.



True South is different from magnetic South. In southeast Pennsylvania, for instance, it is 7 degrees West of magnetic South. It is better to orient a little East (i.e., 10 degrees) to facilitate more solar energy earlier in the day and warm up the high tunnel quicker.

Capacity of Soil to Support the Structure

Most greenhouses and high tunnels use ground posts that are installed into the ground two to four feet deep. Ledge, boulders, coarse stone, or other obstructions can hamper installation. If rock cannot be removed, holes must be bored with a rock drill as Ed Weaver did in constructing his multi-bay high tunnels.

A firm base is needed, especially at the bottom of the ground pins and concrete. Extensive excavating and/or previous fill must be completely settled or the ground pins will need to be placed to an undisturbed depth to avoid settling of the high tunnels.

Agricultural Capacity of the Soil

As a base, any coarsely textured, well-drained soil should be appropriate for high tunnel production. Clay soils are the least desirable base for high tunnels because they don't drain well, thus remaining colder, and because they are more prone to the build-up of salts *(see salinity discussion on page 56)*. However, growers have been able to make do with a wide variety of soils, amending and improving them as they are able, in order to successfully grow in these special environments *(See "Soil Management" on page 54)*. It is more economical to enrich soil in existing high tunnels to boost yields and enhance plant resilience than to add more high tunnels.

Selecting Your Structure

Setting out to build a high tunnel is no different from any other capital project. The steps prior to construction—planning, financing and funding, and ordering—are often the most difficult. The actual building project is relatively simple and can be exciting. The completion of any project has rewards of satisfaction and future profit.

In shopping for a high tunnel, and here we focus on single-bay structures, a grower will need to select from an array of designs, sizes, and special features. Different materials and construction methods can also be used. Experienced farmers have weighed the advantages and disadvantages of these options for their climate, markets, production aims, and bottom line.

Quonset or Gothic-shaped Structures?

The shape of a tunnel affects its performance. It will have an effect on lighting (and shading), energy gain, growing space, and ventilation.

Single-bay high tunnels come in two primary shapes: Quonset and Gothic arch *(see diagram below).* The Quonset shape is relatively short and squat with a rounded roof and sloped sides, while the Gothic, like a cathedral, has a high pointed peak and straight sidewalls. Unheated Quonset structures can also serve as cold frames for overwintering nursery stock. Multi-bay high tunnels, including the Haygrove structure described in this manual, are usually a series of interconnected Quonset-shaped tunnels. Gothic type tunnels have several advantages compared to Quonset models. In many circumstances, these advantages easily offset their greater cost.

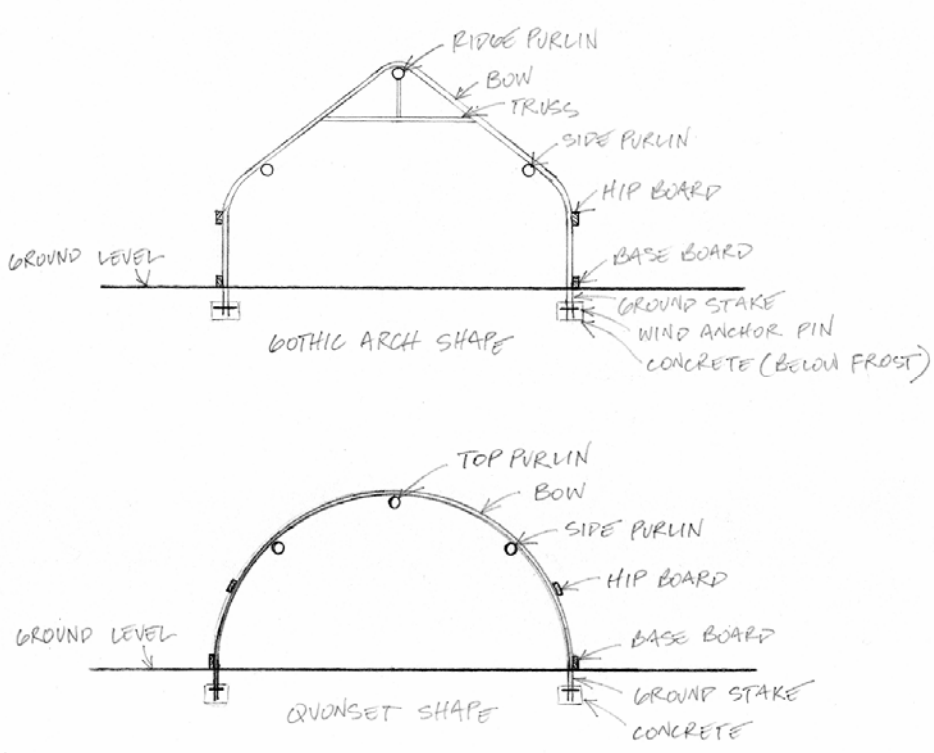
A Gothic-shaped structure readily sheds snow because of the steep pitch of its roof. Quonsets, especially those with PVC bows, need to be swept free of snow to prevent collapse. When snow threatens, some growers set up 2" x 4"s as temporary props under the ridge pole, purlins, or bows of their Quonset-shaped high tunnels. PVC tunnel owners are wise to remove their plastic for the duration of the snowy season.

Match your structure's design load to local conditions of snow and wind. Some greenhouse suppliers can select design specifications appropriate to your county. In the first winter, one northern farmer's high tunnel—purchased from a southern supplier—was destroyed in a snowstorm, along with the perennial plant material inside.

The taller sidewalls of Gothic tunnels offer more usable space along the sides for crop production and growth and for working comfort. For trellised crops like tomatoes, Gothic-style tunnels provide adequate height both for the interior and perimeter rows. The headroom over the edge beds in a Quonset tunnel may be so low that even a short person is uncomfortable when using a walk-behind seeder, for instance.

The Gothic shape also contributes to better air exchange and moisture control, and thus a superior growing environment. The greater height of Gothic tunnels allows for better ventilation through higher gable-end vents. Gothic arch roofs tend to have enough of an angle to help shed water that condenses on the interior, instead of dripping on the plants below.

In Quonset tunnels, since the whole structure is curved, opened roll-up sides expose some of the crops growing along the side to precipitation and other adverse weather conditions. This defect can be partially alleviated by purchasing extended ground posts.



Footprint

High tunnels come in many sizes, in widths from 14' to over 40' and in incremental lengths. A width to length ratio of 1:2 is ideal for passive solar

gain *(See Mazria's "The Passive Solar Energy Book").* However, you get more for your money with a 30' x 96' high tunnel than a 30' x 60' structure.

Narrower tunnels will experience more heat loss than wider tunnels because of their perimeter to growing area ratio. A 10' x 90' tunnel has a 200' lineal perimeter and a 900 square foot growing area, whereas a 30' x 70' tunnel also has a 200' lineal perimeter and 2,100 square foot growing area. The second structure has 133% more growing area, and less than half the ratio of perimeter (or heat loss potential) to growing area. Wider tunnels also tend to be taller and provide improved ventilation and interior air circulation.

Under northern growing conditions, even 30' wide high tunnels can be sufficiently ventilated with roll-up sides and large gable-end vents and doors. In warmer climates, in tunnels with tall, dense crops like tomatoes, narrower tunnels (20' to 26') may more effectively reduce stale air in the middle of the structure without mechanical ventilation.

Size

How big should your high tunnel be? Consider not just how much growing space you expect to use now, but also what you'll want a few years into the future. A well-built tunnel will last at least 20 years.

Another important factor in determining the size of high tunnel to purchase is the amount of additional workload you are prepared to take on. Steve Moore estimates that a 30' x 96' high tunnel that is intensively planted with multiple crops can take 10 hours or more of labor each week after initial set up and skill development. Marketing time is additional. When a farm uses a simple cropping pattern, like Slack Hollow Farm's winter spinach system, regular management time can be greatly reduced.

To get the most from your investment, it might make more sense to start with a short, wide house (i.e., 30' x 48') and add on later than to buy a 16' x 96' high tunnel that may quickly outgrow its usefulness.

Also when determining the size of tunnel to build, take into account how the structure will fit on your property. What are the site possibilities? How much land is available and what is its topography? It is critical to have enough room around the tunnel for easy access with vehicles and equipment, snow removal, water drainage, and ventilation; to avoid shading; and to allow for future expansion *(See "Site Considerations" on page 26).*

Selecting Materials

The Frame

Historically, wood was commonly used to frame greenhouses, but it is has gone out of fashion because of its relatively high maintenance cost and the availability of steel greenhouses. Pete Johnson, a year round grower in North-central Vermont, is an exception. He is currently growing tomatoes and salad crops in a very large high tunnel which he framed with Eastern white cedar and other local trees. For most growers, steel is the best material for a high tunnel frame. The best greenhouse structures are made of high tensile strength steel covered with a very good galvanized coating to prevent rust.

An alternative to steel for the structural members of a high tunnel is polyvinyl chloride (PVC) pipe. Price is PVC's only real advantage compared to steel. Mainly it is used in farmer-built tunnels. Tunnels whose bows are made of PVC pipe are more prone to collapse under snow load and wind. Only narrow high tunnels with a Quonset-shape and smaller walk-in or caterpillar tunnels can be constructed of this weaker material. It should be noted that PVC is a persistent poison that harms human and animal health and pollutes the environment during manufacture and disposal *(See "The Trouble with PVC" on page 31).*

Bow spacing will depend upon the overall design of the tunnel, the anticipated snow load, and the strength and capacity of its component steel. Although a 4' bow spacing is used fairly commonly, with trusses placed on every other bow, growers are increasingly turning to 5' bows that utilize trusses on every bow.

(See "Bending your Own Frames" on page 43.)

Baseboards and Gable-ends

Most high tunnels use wood for baseboards, hip boards and gable-end framing. For the gable-end, another option is steel. While more costly, it will not need to be replaced and is easy to work with. For the baseboard, recycled plastic lumber, that is rot and insect resistant, is another comparatively expensive alternative.

In selecting the type of lumber to be used for the baseboard and hip board, consider their rates of decay. Finding lumber that is affordable, durable, and sustainably harvested is a challenge and trade-offs are inevitable. For example, redwood is very expensive and unsustainable.

Other more accessible choices, (depending on location) include rot-resistant wood species such as the cedars, cypress, black locust, and Osage Orange. White oak can also be used, though it will need to be replaced after about eight years, the second time you replace the tunnel's polyethylene film. Cheaper but less attractive options are hemlock, pine, and spruce, listed from most to least rot-resistant.

The Trouble with PVC: A Cheap but Unsustainable Material

Polyvinyl chloride (a.k.a. vinyl or PVC) is a chlorinated hydrocarbon, like DDT and dioxin. During PVC production and disposal, very large quantities of hazardous organochlorine chemicals are produced unintentionally and released into the environment. As a result of its intrinsic hazards, PVC is under intense scrutiny in many countries, by governments as well as environmental and health advocates.

PVC is virtually impossible to recycle because each PVC product contains a unique mix of additives. Even in Europe, where PVC recycling is more advanced than in the U.S., less than 3% of post-consumer PVC is recycled. And even most of this tiny fraction of PVC is merely "down-cycled" into other products, so the amount of virgin PVC produced is not reduced.

The production of chlorine for PVC uses as much energy as 80 medium-sized nuclear power plants would generate. Chlorine production is an extremely energy-intensive process that consumes about 1% of the world's total electrical output.

Among the toxic chemicals produced during the PVC lifecycle are chlorinated dioxins, chlorinated furans, PCBs, hexachlorobenzene, and octachlorostyrene. Workers and communities are exposed to high levels of the toxic substances released into water, air, and soil due to PVC production. These toxic substances are also released when PVC is incinerated.

As a group, toxic by-products of PVC production are highly persistent. These chemicals do not degrade in nature, so they build up in the environment. Transported by wind currents and water, their presence has been documented even in the most remote regions of the globe.

Since these chemicals are fat-soluble, they build up in the tissues of living organisms. In species high on the food chain (like humans), the levels of these chemicals can be millions of times greater than in the environment. In mammals, these chemicals easily cross the placenta and concentrate in breast milk.

Some of the toxic chemicals produced when PVC is made are dangerous even at extremely low doses. For instance, at doses in the low parts per trillion, dioxin causes damage to fetal development, and the immune and endocrine systems, and impairs reproduction. Cancer and brain and nervous system damage are also associated with exposure to these organochlorines.

In its pure form, PVC is rigid and brittle. To make flexible vinyl products, large quantities of plasticizers called "phthalates" are added. Phthalates cause cancer, infertility, testicular damage, reduced sperm count, suppressed ovulation, and abnormal development of male reproductive tract in lab animals. Like the organochlorine byproducts of PVC production, phthalates are pollutants that bioaccumulate (i.e., persist in the environment) and are found in the tissues and fluids of the human population. As they are not chemically bonded to PVC, but merely mixed in when the vinyl is formulated, they eventually leach out into air, water, and other substances with which the vinyl comes in contact.

Pure PVC is not stable, so lead, cadmium, and organotins are added to stabilize vinyl used in construction and for other extended-life applications. These stabilizers, which are toxic and persistent in the environment, are released when vinyl is formulated, used, and disposed.

(Source: Thorton, PhD, Joe. Environmental Impacts of Polyvinyl Chloride Building Materials. A Healthy Building Network Report.)

Due of the dangers of exposure to human and animal health, CCA (chromated copper arsenate) pressure-treated wood has not been produced for most residential and general consumer uses since 2004**.** Two Canadian government agencies, Environment Canada and Health and Welfare Canada, consider arsenic to be a "non-threshold toxicant" (i.e., a substance for which there is believed to be some chance of adverse health effects at any level of exposure). Arsenic leaches out into soil and is taken up by plants. Organic farmers are prohibited from using arsenic-containing pressure-treated lumber.

Borates are one of the arsenic-free wood treatment alternatives already on the market. Treating oak with approved borate products may lengthen its lifespan to 12 years. Steve Moore has treated oak with sodium tetraborate and sodium octaborate, both of which may meet organic standards if from mined sources. He uses these food grade borate products as they can be readily and inexpensively obtained from local chemical suppliers. Borate wood preservatives such as Boracare can be purchased from pesticide distributors. They penetrate into the wood much more effectively than the food grade materials dissolved in water.

End walls can be made of plywood (painted is best), twin wall polycarbonate sheets ($1.50/ft^2), other structured sheets, or just polyethylene film ($0.10/ft^2). Of course, opaque materials like plywood prevent light transmission.

Twinwall polycarbonate is an extruded ribbed high-tech plastic with double walls for added insulation. It is sold as structural sheeting. For high tunnels, it has an application for the gable-end walls. As a hoop house covering, it compares favorably with both polyethylene and glass. It transmits up to 83% of light (more than two layers of polyethylene film),

and insulates 40% better than glass, but weighs one-sixteenth as much and won't shatter. It is very durable and cuts easily with a saw. It is far more expensive than poly but costs less than glass.

Plastic Film

By far the most common covers for high tunnels of all types are made of polyethylene. UV resistant greenhouse-quality polyethylene is far superior to common construction-grade polyethylene. It transmits light better; is more resistant to wind, heat, and yellowing; and has a longer life.

It is important to replace poly film as recommended. For instance, after four years, standard 6-mil plastic loses about 15% of its ability to transmit light. This is particularly significant during winter production, especially in cloudy climates.

Greenhouse film treated with anti-condensate additives prevents condensation drips. Infrared re-radiant (IR) materials are added to film to reduce overnight heat loss. In the U.S., metal halides are typically used to treat the film, while in Europe phosphorous and boron compounds fill this function.

Chris Wien, at Cornell University, points out that "films that lack an additive which blocks infrared radiation can allow so much heat to escape on cold clear nights that temperatures in high tunnels are lower than they are outside the tunnel. You can have instances in which the plants inside freeze before plants just outside the greenhouse. It is very important that polyethylene films used on high tunnels have an infrared blocker added to prevent such a problem."

Anecdotal evidence suggests that the frost forming on the inside of the plastic on a high tunnel is an excellent reflector of infrared radiation. Steve Moore thinks that it may be equal in value to special infrared AC plastic in unheated structures. In heated structures (where the interior frost is not present), infrared AC plastics undoubtedly retain heat better.

New designer greenhouse films are now entering the market. When the Cramers replaced the film on their Haygrove multi-bay tunnel, they chose *Luminance THB* (thermal heat barrier) poly which costs 10% more than ordinary greenhouse film *(See www.bpiagri.com/hort-luminance.htm)*. Using infrared blockers, this enhanced poly reduces excess daytime heat and scorching while also helping to minimize heat loss at night. It also increases light diffusion, making more light available to plants to increase photosynthesis and yields. In particular, it is recommended for ornamentals and nursery stock and has been shown to improve tomato yields. However, the manufacturer cautions that it is not the best choice for early spring growth.

Steve Moore experimented with several types of plastic film over a multi-year period on two adjacent high tunnels. He compared double layers (inflated) of the standard 6-mil 4-year film with infrared re-reflectants and anticondensate to single layer *Coeava*, a 7.8 mil film with reportedly an 8-year useful life.

In south central Pennsylvania, a high tunnel with two layers of 6-mil, 4-year standard poly was warmer by an average of over 6°F during the winter, and had superior plant growth compared to high tunnels with a single layer of 7.8 mil high performance plastic. Steve suspects that this difference in thermal performance between the two types of film would be less significant in a warmer climate or under late fall or early spring conditions.

In carrying out this experiment, Steve had thought that the lower insulating ability of a single layer of poly could be offset by using more layers of row cover inside the structure. He also hoped to gain the benefit of enhanced light transmission and save money by not using another layer of high tunnel covering. But neither of these theories proved correct. In the dead of winter, the double walled tunnel stayed warmer and outperformed the single layered tunnel.

Double Versus Single Layers

A double layer of poly film with inflation between the layers provides insulation and reduces heat loss by 40% according to Aldrich and Bartok (see NRAES publication, "Greenhouse Engineering,"). Along with increasing heat retention, the second poly layer reduces the light level by about 10% so a balance must be reached. Low light levels cause plants to become weak and leggy, and slow down growth. As an alternative to double poly layers with an inflation fan, some farmers use multiple layers of floating row covers, which more drastically decrease light transmission. Unless these covers are removed during the day, crop production may suffer.

Many farmers have found it sufficient to use a single layer of polyethylene on their high tunnels. However, in the winter, these high tunnels will have greater heat loss and will be colder than tunnels with a double layer of poly. And where a heating system is used, significantly more fuel will be needed if just a single layer of poly film is employed. Using a double layer requires electricity to run a small blower fan. An alternative to being connected to the electrical grid is a modest solar power system. *(See "Photovoltaic Inflation Systems" on page 48 and "Getting the Right Pressure on Your Inflation" on page 46.)*

Disposal and Recycling of Agricultural Plastic Films

Plastic film must be disposed of when its useful life is over, presenting the

farmer with a disposal problem. Polyethylene covers on high tunnels and greenhouses make a significant contribution to the growing problem of waste plastics. Polyethylene film has rapidly replaced more durable materials in many farm applications. Plastic bags and covers are used to store hay and ferment animal feeds such as silage and haylage, and palletized goods are shrink-wrapped. Most of these plastic films are produced from low-density polyethylene (LDPE #4) resins.

The most environmentally sound disposal option for these plastics is recycling, which is discussed below. Most agricultural plastics are not recycled, however, in part because recycling opportunities are few and far between. Surveys in New York and Pennsylvania suggest that about half of agricultural plastics are burned and the remainder are buried or dumped on-farm. These states, like many others, do not restrict the on-farm disposal of plastics. Therefore, farmers have no economic or legal incentive to transport these materials to a regional transfer station or other central collection facility for recycling or controlled disposal (at a landfill or incinerator).

Burning agricultural plastics in open fires or burn barrels is a burdensome and unpleasant job. It is also highly polluting and carries short- and long-term health risks. A chemical fact sheet cautions firefighters to wear a self-contained breathing apparatus where there is a risk of exposure to burning polyethylene and states that fumes from molten or burning polyethylene can cause respiratory irritation, headache, and nausea.

Low temperature combustion of plastic film that occurs in on-farm burning produces soot and other noxious emissions and also leaves toxic residues. These emissions are far in excess of those released by municipal waste incinerators that burn at very high temperatures and are equipped with mandatory pollution control devices. An early 1990s study for the US EPA reported that 20 times as much dioxin, 40 times as much particulate matter, and many times more metal emissions resulted from open burning of household waste in barrels compared to municipal waste incinerators.

Since that study, the gap in emissions from open burning versus incineration has grown exponentially due to stricter pollution control standards for incinerators imposed since 1995. Between 1990 and 2000 emissions of toxic compounds called dioxins and furans declined by about 99% and heavy metals by more than 90% in 66 large municipal waste incinerators.

On-farm burial removes refuse from sight, but decomposition is extremely slow and the potential exists for movement of water-soluble breakdown products into groundwater. Leaving discarded plastic lying around is unsightly and gives a negative impression about agriculture. Pools of water that form in the plastic film serve as mosquito breeding grounds.

Municipal disposal in landfills or incineration is a better alternative for disposing of waste plastics than on-farm burning, burial, or non-disposal. Farmers often reject this option because of the expense, time, and logistics involved.

Another disposal method—pelletizing waste agricultural plastic into fuel nuggets—has been under investigation by at Pennsylvania State University researchers since 1995. The "densified" fuel pellets would generate energy when burned with coal in boilers. These pellets would also eliminate the problem of densely compacted plastic bales causing "hot spots" that damage incinerator equipment.

When highly contaminated plastics are used to make the pellets, more toxic emissions result, sometimes exceeding regulatory limits. One hypothesis is that dirt and debris limit air movement to the combustible materials—a problem that increases when plastic mulches are wet.

Originally researchers envisioned "co-firing" small burners with these waste plastic pellets and coal for heating greenhouses and for other farm applications. But pollution concerns may require that the pellets be burned as a tiny portion of the total mix in a large industry or municipal incinerator. The toxicity of ash from burning plastic fuel pellets on the farm is another area of concern.

Recycling is a superior way to dispose of agricultural plastics. Recycling programs are underway in the Northeast US and Canada for handling most types of plastic resins used in agriculture, though their geographic coverage is spotty. In the absence of such a program, some farmers are stockpiling their waste plastic film until they have access to a recycling program. A trip to purchase equipment or supplies may serve as an occasion to bring waste plastic to a distant recycling program.

In the Northeast, two successful agricultural plastic recycling programs stand out as models for government initiatives and individual entrepreneurs. A polyethylene nursery film collection program was started in New Jersey around 1997. This state-run collection program collects "clean" bundles of nursery and greenhouse films. Its Mt. Holly site accepts film from out-of-state growers. In its first five years, with 100 to 125 growers participating, almost 1.8 million pounds of nursery film was recycled. The $20 to $25 per ton fee is substantially less that the $60 per ton landfill tipping fee.

With an initial aim of reducing farmers' tipping fees, Lancaster County farmer Daniel Zook started a viable agricultural polyethylene collection business that is now actually paying $80 to $100 a ton for waste polyethylene. In 2005 (its fifth year), Zook Plastic Recovery sold 500,000 pounds of plastics. Zook set up the program with Trex, a company that reprocesses the material into plastic lumber for decking. Besides guaranteeing a market, this firm guided Zook through start-up and helped him purchase a cardboard baler. Zook holds month-long waste plastic collection drives each spring and fall and for a couple weeks in the summer. He also accepts plastic at other times. After he bales this plastic, he has it hauled to a Trex factory in Virginia.

A 2003 Cornell report lists several other agricultural plastic recycling efforts. A plastic lumber re-processing facility based in Prince Edward Island, Canada, is capable of handling "dirty" LDPE plastics used in dairying. A nationwide, industry-sponsored network collects high-density polyethylene pesticide containers. In the US and Canada, an industry-sponsored program based in Ontario, Canada, picks up, pays for, and re-processes polystyrene nursery flats and trays.

The recycling of agricultural plastics lags behind other types of recycling due to several barriers. Municipal waste transfer stations cannot easily accommodate loose plastic film, which is bulky and difficult to handle. Any collection site must be equipped to bale the material separately.

The quality of agricultural plastic film is often compromised by contamination of dirt, moisture, or debris. Contamination reduces the marketability and/or the price paid. For example, the Trex Company pays less than one-fifth its standard rate for plastics that require pre-cleaning. This company has installed a $10 million wash line to clean dirty plastics and also has a pick line to remove debris.

The black and white agricultural films used for mulch bags and wrapping are not much in demand by plastic recyclers as the pigments must be greatly diluted to manufacture marketable plastic lumber. This is relevant to high tunnel growers because, in many regions, the bulk of agricultural film is used by dairy farms and feed producers, and greenhouse film alone might not be abundant enough to support a collection program.

Agricultural plastics are also more costly and inefficient to collect than urban plastics, because they are dispersed across the countryside and farmers dispose of these plastics sporadically and seasonally. Since concentrated quantities of agricultural plastics are more attractive to recycling markets, recycling programs may need to be organized into regional or statewide programs.

Farmers are more likely to participate in recycling where there is a nearby collection system, where burning and dumping are prohibited, and where tipping fees for solid waste disposal are significantly higher than for recyclables. Regional and statewide recycling programs may be most appropriate given the capital costs for recycling equipment, the sporadic and seasonal nature of plastic removal, the dispersed feedstock for recycling, and the critical mass of materials needed to attract industry.

Despite these challenges, opportunities for new private and public recycling efforts abound. While greater farm use of polyethylene is increasing the magnitude of the disposal challenge, high oil prices are also creating greater demand for waste plastics. Farmers who use agricultural plastics should consider taking an active role in making recycling an easier choice for other farmers in their region.

This section was adapted in part from Levitan, Lois, and Barros, Ana. "Recycling Agricultural Plastics in New York State." March 11, 2003. 2nd ed. Environmental Risk Analysis Program. Cornell University. http://environmentalrisk.cornell.edu/C&ER/PlasticsDisposal/AgPlasticsRecycling/. Personal communications with plastic recyclers and reports from Penn State provided additional background.

Multi-Bay Tunnels

Multi-bay high tunnels are a special category of tunnel. The most prominent manufacturer of this type of tunnel is the British company, Haygrove Ltd. As fruit farmers in Herefordshire, England, Haygrove found single bay tunnels inadequate for field-scale crop protection. With multi-bay tunnels in Spain as an inspiration, it developed its own model.

In Spain, where the climate is mild, multi-bay tunnel frames can be rather weak. Haygrove tunnels improved on the original Spanish tunnel concept by making them appropriate for use in the U.K. Since they were first introduced in 1996, their use has spread to 30 countries, from Norway to Australia, and by 2006, they were protecting over 7,000 acres of crops.

Like other high tunnels, Haygroves enable the farmer to extend both ends of the growing season. They also prevent rain, wind, and hail damage, reduce pesticide use, and avoid the loss of harvest days due to precipitation.

In terms of environmental management, Haygroves vent more fully than typical single-bay high

tunnels. Haygrove's lacing system holds the polyethylene cover securely in place while allowing a grower to vent the tunnels up to 8' or 10' high. This design feature virtually eliminates the problem of excess tunnel heat and humidity.

Haygroves are three-season structures. They are not designed to support a heavy snow load. In temperate regions, the polyethylene film should be removed for the period of time during which snowfall is possible. The film is "hibernated" by pulling it off the hoops, down onto the Y of the legs, and covering it with black plastic that is secured with twine. This eliminates any chance of snow damage to the tunnel and protects the film from UV exposure when not in use. At the beginning of the next growing season, the film is remounted on the hoops and secured with the rope lacing.

Haygroves can withstand relatively high winds. Each Haygrove leg and anchor has an auger welded to it, and these are drilled 30" into the soil; cement is not used. This keeps Haygrove tunnels from lifting out of the soil, something that can happen with single bay tunnels that are not cemented into the ground. During high winds, Haygroves should be left fully vented. This decreases pressure on the tunnel by allowing some of the wind to move through the tunnel while still shielding the crops from its full force.

Most growers in temperate climates vent (open) and close their tunnels every day for the first six weeks or so of the season and then leave them completely vented for the majority of the growing season. No special attention to venting is required during the period when severe thunderstorms are most likely. Daily venting and closing is again practiced during the fall.

Haygrove tunnels concentrate the run-off in the leg rows between the bays, and this water must be controlled. Prior to construction, most growers form shallow swales that are covered with weed barrier cloth. The legs are then drilled into the soil through small slits in the cloth.

Haygroves are sold in various bay widths and heights to accommodate a range of needs. The structures are tall enough for tractor access and dwarf tree-fruit production. The Haygrove design allows adjacent bays to be managed for different microclimates, with curtains dividing bays with cool and warm crops. The configuration of these tunnels provides for easy expansion of growing area to the sides or ends.

These tunnels retail for about half the cost of traditional, single-bay high tunnels. The minimum Haygrove purchase is a half-acre; however, a full trailer load contains two acres and the delivery cost is the same whether the trailer is full or not.

Construction time is faster for these multi-bay structures than for traditional high tunnels. Typically, growers report 250 to 300 man-hours to construct an acre-sized Haygrove compared to 75 or 100 hours for a 30' x 96' tunnel (1/12th acre). Construction involves relatively few tools and no lumber. Along with delivery, Haygrove provides on site hoop bending and construction training for customers. Since these tunnels follow the natural contours of the land, there is no need for heavy equipment to prepare a level site.

Inferior Multi-Bay High Tunnels

One farmer decided to buy a less expensive multi-bay structure to save money, and regrets his purchase. Rob Hastings, the owner-operator of Rivermede Farm in Keene Valley, New York (in the Adirondacks), may be one of the most Northern-most farmers in the Eastern U.S. to grow crops in a multi-bay high tunnel. He grows fall raspberries, everbearing strawberries, and cut flowers (for October weddings) in the structure and also has five heated and unheated single bay high tunnels.

After going on the Haygrove grower tour in England, he was sold on this type of high tunnel. Based solely on economic considerations, he opted to buy a cheaper model from another company (which we will refer to as "Brand X"), instead of a Haygrove, which it superficially resembled. He purchased a four-bay structure that covers a quarter acre for under $7,000; each bay measured 26' x 100'. A Haygrove covering a third acre would cost $12,000, in part because the shipping is the same whether one buys an acre or a fraction of an acre.

"There are many subtle differences that you can't see in the catalogue," says Rob, explaining his disappointment at the weaknesses of the structure he selected. He has had to modify and reinforce the high tunnel in order for it to function. Contrasting the two companies, he characterizes Haygrove as "farmers turned metal benders" and Brand X as "metal benders who happen to make products for farmers."

While on the tour in England, he watched how quickly the Haygrove went up. The Brand X structure took much longer to assemble and construction was far from smooth. "There is no comparison," Rob observes. A major difference is that Haygroves can be constructed out of extra-long pieces because they are shipped from the United Kingdom in a container and then delivered as a unit to the customer. Haygrove personnel come and bend the hoops on the farm.

Brand X's multi-bay high tunnel consists of multiple pieces that need to be bolted or screwed together. For

instance, there are five pieces in each Brand X hoop while a Haygrove hoop comes as a single piece. “I had to find a flat surface on the farm to assemble the hoops so they would not be twisted.” Each of these joints presents a weak spot, and Rob has experienced a plethora of failures around these joints. “I had to double screw every hoop where it joins the Y post,” he says. “It either tore out the tek screw or bent them.”

Rob has identified various annoying design flaws in the Brand X. In a Haygrove the hoops rest on the Y post and no water can get in and freeze. The Brand X structure allows water to enter and freeze. Haygroves have a peg at the top of each Y post for tying the rope to that keeps the plastic film on. The Brand X lacks the peg and there is nothing to tie to.

The Haygrove has an effective way to finish off the end walls ands simultaneously provide wind bracing. The Brand X structure comes with a reinforced plastic end wall which has not been satisfactory. “The flopping plastic acts like a gigantic sail tied down with an anchor,” observes Rob. He plans to do some cross bracing to shore up the plastic.

The lack of technical support is another major frustration. “Brand X barely knew I had bought one,” he says. “When I called, I was talking to someone who was clueless and who was not a farmer.” Rob recommends other farmers learn from his mistakes and “invest in the best.” “I’m sorry I didn’t ask questions,” he concludes.

Single-Bay Tunnels in the Haygrove Style

Haygrove’s newest product is the “Solo” single bay tunnel. It comes in sizes appropriate for the smaller grower. Typical dimensions are 24' x 200' and 28' x 200", though various widths and lengths are available. This Quonset-shaped structure is built of 14 gauge galvanized steel hoops. Its poly cover is secured to the framework with the same rope lacing system used on Haygrove’s multi-bay tunnels and therefore provides excellent venting. With a minimum 10' height at the peak, it has a large air volume for its size. Being a single-bay tunnel, the Solo seals well for maximum season extension. Like other Haygroves, it is sold as a three-season structure and is not engineered for snowload.

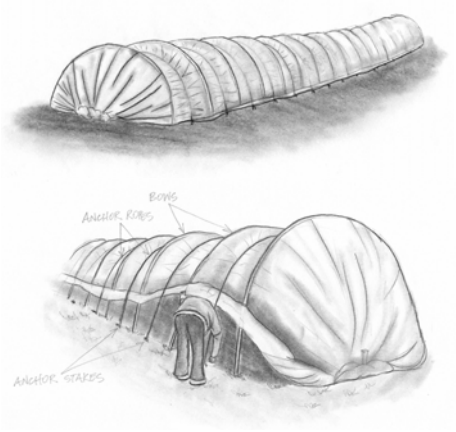
Solos can be erected on hills or uneven sites and compared to other single-bay tunnels, much less construction time is required. As with Haygrove’s multi-bay high tunnels, no carpentry or extra materials are required. While Solos are single-bay tunnels, they can be built on double prong anchors (8" between bays) to cover large areas.

A Solo package, including the poly film cover and 12 mil roll-up doors for both ends, costs about $1 per square foot, or about half the cost of a more conventional high tunnel.

Walk-in Tunnels (Caterpillars)

Walk-in tunnels are inexpensive alternatives to the greenhouse-like structures that come to mind when thinking about high tunnels. For an equivalent area under cover, they cost less than a quarter of the price of a more traditional high tunnel. With respect to environmental modification, they are intermediate between traditional high tunnels and the low tunnels commonly used by vegetable growers. *(See “Low Tunnels” on page 38.)*

Due to their segmented appearance, some growers call these structures “caterpillar tunnels” *(see diagram)*. They have been used to grow vegetables, cut flowers, greens, and herbs.



The size of walk-in tunnels is variable. They range from 8' to 18' in width and cover two to four beds. Their length may be from 24' to 300' or more, depending on the length of beds they are intended to cover and limits to the sizes of available covers. The flexible tunnel length enables a grower to construct a walk-in tunnel virtually anywhere on the farm because it can be sized to fit into a farm’s existing bed system. The tunnels are tall enough to walk in and are accessed by ducking under the sides anywhere along their length (hence their name).

Bows for walk-in tunnels may be made from PVC, electrical conduit, or galvanized steel hoops. To erect the tunnel, the bows are either slipped over ground stakes made of rebar or tubular steel, or the bows are set directly into the ground about a foot deep. Bows are spaced six to ten feet apart, depending on the site’s wind exposure. It is best not to construct the tunnel broadside to the wind, but if that is unavoidable, the tunnel will serve as an effective windbreak for crops planted on its lea side.

A 1/4" rope tied from hoop to hoop is used to form a ridge purlin. The purlin is attached to heavy-duty ground stakes at both gable ends. The structure is quite “loose” when uncovered; much of the tunnel’s structural integrity comes from the

cover and the way it is secured to the ground.

Walk-in tunnels may be covered with greenhouse plastics, heavy spun-bonded fabrics such as Typar, or shade cloth. The cover should be matched to the intended use of the structure. The less expensive Typar might be the better choice, for example, if the goal is to give a boost (or provide insect protection) to cool-season crops such as spring greens. Greenhouse plastic would be the better choice for an early planting of tomatoes. And shade cloth might be selected for rooting strawberry tip cuttings.

The covering is held fast by 1/4" ropes that are drawn over the top of the structure (Canastoga wagon-style) and are secured to stakes or earth anchors in the ground. These ropes give the structure its segmented, caterpillar-like appearance. The edges of the plastic are left loose, but the covering should be sized so that there are at least two feet of extra material on each side. In particularly windy locations, the covering may be secured by placing rocks or small sand bags on the edges of the plastic. At the gables ends, the plastic is bunched together using rope, and the rope is tied to a secure stake. The tunnel's dimensions should be configured to fit commonly available greenhouse films or floating row covers.

While they have many advantages, starting with their cost, walk-in tunnels are really three-season structures. The wide bow spacing that keeps them cost-effective greatly reduces their snow load capacity, so the covering should be removed before winter. However, walk-in tunnels with a bow-to-bow spacing of 4' and a width of 10' have reliably withstood snow.

Walk-in tunnels must be ventilated manually to avoid excessive temperatures. During the coldest periods of the year, sections of the sides (the cover) are propped up with short "Y" shaped props or branches cut for the purpose. When temperatures warm, the sides may be rolled up along the entire length of the tunnel. Clamps or tall "Y" props can help hold the rolled up plastic in place. The sides must be rolled down when high winds threaten.

These tunnels are highly portable. They may be erected and dismantled relatively quickly. For example, two 200' long units built to cover three beds of lettuces were erected by Ted and Jan Blomgren and a co-worker over the course of a morning.

One way to reduce the annual costs of construction and dismantling is to leave the caterpillar tunnel in place from year to year, and to develop a list of tunnel crops around which a crop rotation plan might be developed.

Walk-ins are highly adaptable structures. They may be built over existing crops, or over bare ground for a later planting. They may be built in the fall, left uncovered during the winter, and then covered in the spring for an early planting. Or they may be used to cover tomatoes during the spring and summer, and then taken down and reconstructed over an existing fall spinach crop.

Caterpillar Tunnels at Windflower Farm

Ted and Jan Blomgren have found many uses for walk-in tunnels to produce vegetables and cut flowers. On Windflower Farm in Easton, New York, they construct some of their caterpillars with metal bows spaced 10' apart, and others using PVC bows spaced 6' to 8' apart. At any given time in the growing season, the Blomgrens may have as many as 9,000 to 12,000 ft^2 of walk-in tunnels on their farm, with the typical tunnel 200' long. Most are covered in 6 mil greenhouse plastic obtained from Farm Tek, "the only source of very long plastic" of which they are aware. Their other walk-ins are skinned in Typar.

Caterpillars have become important on Windflower Farm because they are easy to construct and cover, and are inexpensive, while providing many of the benefits of a multi-bay structure like a Haygrove. Steel hoops and plastic film for one of their 16' x 200' tunnels cost them about $1,500, about one-third the cost of a Haygrove multi-bay high tunnel. In addition, air flow in caterpillars is excellent—better than in a more expensive, conventional high tunnel—as caterpillars open fully like a Haygrove. (But unlike a Haygrove, management of high winds in a caterpillar requires closing the sides.)

To get high quality fruit early from their first planting, Ted and Jan transplant zucchinis and cucumbers into walk-in tunnels on May 1. These tunnels span three beds that are six feet on center. Early harvests of both of these vegetables are important in meeting their goal of delivering a diversity of "real vegetables" (as opposed to salad greens) to their New York City-based CSA membership.

Cucumbers, planted two rows per bed into black plastic (or six rows across a tunnel), start yielding a substantial harvest by the end of June. The zucchinis go into bare ground, with one row running in the middle of each of the three raised beds. Each row of zucchini is sandwiched between rows of quick Asian greens. These greens will be harvested by the middle of June just as the zucchinis are filling out the space. By the end of the first week of July, the zucchini harvest is going strong.

On May 1, tomato transplants are planted into three beds in walk-in tunnels for first harvest in July. Using the hybrid variety 'Mountain Spring' as their mainstay, Windflower Farm

gets a high quality fruit that bears well over a long period of time. In 2005, they harvested from their May 1 planting until late October. They have also produced eggplants and bell peppers in walk-in tunnels.

The Blomgrens initially experimented with walk-in tunnels to protect China asters from aster yellows, a disease transmitted by leafhoppers. The alfalfa fields that surround Windflower Farm are leafhopper habitat. Ted says they skinned these tunnels with Typar because "We thought we could get away without rolling up the sides," something that wouldn't be possible for plastic-covered tunnels which trap heat more effectively. "Now, tarnished plant bug is our only insect problem," says Ted.

Besides preventing aster yellows, the tunnel environment produced China asters with stems three feet long. Short-stemmed cut flowers are not desirable and Ted and Jan realized that the extended stem length was a benefit that tunnels could provide other cut flowers. The absence of wind and reduction of light in the walk-in tunnels are two factors associated with longer stems.

Windflower Farm currently grows stock, snapdragons, godetia, larkspur, Bells of Ireland, and lisianthus in walk-in tunnels to achieve much earlier blooms and longer stems. They have come to prefer walk-in tunnels to regular high tunnels. They are also convinced that plastic film is superior as a tunnel cover to Typar except for mid-summer production. In the summer, they use Typar to protect against insects, diffuse the brightness of the sun, and shelter the flowers from wind.

Though they are moving away from Typar, Ted stresses that it has two virtues. It costs about half as much as plastic, and its light weight makes it easy to use. "I can cover a 200-foot tunnel myself," he said. It takes a minimum of two people to install a plastic cover.

On walk-in tunnels built for fall lettuce and salad mix, they may still use Typar as the cover. Ted and Jan sometimes build tunnels over beds where they have already set transplants. Using a marking rod, they pound in stakes at 10' intervals and then lower hoops over the stakes. For an inside cover, they use a midweight fabric, such as 0.9 ounce Covertan, suspended over low wire hoops. They harvest mature lettuce from these unheated tunnels as late as Thanksgiving. Ted cautions that this design has no capacity to bear snow.

Caterpillar Tunnels at New Minglewood Farm

In 2004, Chris Lincoln grew half his tomato crop at New Minglewood Farm in walk-in tunnels. Better yields and a higher percentage of #1s have convinced him to raise his entire tomato crop in these tunnels. This year, he used four 100' long tunnels to grow 800 row feet of heirloom tomatoes for retail sale at a farmers' market and to restaurants.

Chris notes higher yields, higher quality, a longer harvest season, and cleaner fruit as benefits of growing fresh market tomatoes in these tunnels. He also counts the low cost of the tunnels and the ease of moving them to different sites on the farm as advantages to walk-in tunnels when compared to more permanent, stationary high tunnels.

Getting earlier tomatoes was not the overriding factor in adopting this growing environment. New Minglewood's typical tomato schedule (reported for 2005) is as follows: Seed on March 28, transplant on May 16, begin picking on July 23, last harvest on October 18, first killing frost on October 21.

In 2005, they sold 5,885 pounds of tomatoes with an average of 11.8 pounds per plant on their 500 plants. (Production varies considerably among the diverse heirloom varieties grown at this farm.) At $3/lb. for #1 fruit, and $2/lb. for seconds, Chris and his wife, Tammara Van Ryn, grossed almost $16,000 on this crop, produced in one-eighth of an acre of caterpillar tunnels.

Chris used 1-1/2" diameter Schedule 40 PVC pipe, rather than steel, for bows. The bows are spaced every 6' and placed on rebar stakes, with a rope and another pair of stakes in between. His tunnels are 10' wide, which allows just two rows of tomatoes per tunnel.

Ideally, he said, the tunnel would be 2' wider, with a corresponding increase in height to accommodate the indeterminate varieties that he grows. As it is, when the plants fill out, they are a bit crowded and grow into the sides and roof of the tunnel. The actual size is perfect for determinate tomatoes, which he does not grow.

Wind is the biggest threat to the walk-in tunnel design, but built properly, they seem to hold up adequately. Unlike a more conventional high tunnel, where the plastic is attached directly to a steel frame, walk-in tunnel plastic is held down by ropes secured to the earth by means of rebar stakes or earth screws. Like the Blomgren's structures, Chris uses ropes over top of the plastic and secured to long rebar stakes driven deep into the ground. If these ropes are not secure, wind can cause damage. To prevent wind damage, it is critical that these anchors are long and stout enough to hold the ropes.

Chris believes that walk-in tunnels have been more time-consuming for New Minglewood Farm than regular hoop houses would be. This is mainly due to the labor involved with setting up and covering these tunnels before tomato planting and disassembling

them later in the year after the plants have been removed.

Another regular task during the spring and fall is opening and closing the sides, depending on sun, rain, and temperature. To vent, Chris rolls up the plastic and clips it to a rope. Once the weather warms, the sides stay up all summer.

In 2006, Chris mulched with black landscape fabric. He used a weed barrier fabric to accelerate tomato development, suppress weeds, and prevent soil splash on the plants. He chose a 6' wide fabric and covered the 2' wide space between tunnels as well as all the ground inside of the tunnels, enabling him to locate the tomato rows at the intersection of two pieces of the fabric. This arrangement eliminated the need to burn or cut plant holes into the fabric.

Low Tunnels: An Alternative to High Tunnels

In some climates, low tunnels can be an inexpensive alternative to high tunnels for cold weather season extension. Low tunnels are simple, protective structures consisting of wire hoops covered with polyethylene or fabric row covers. Though more labor intensive, with well-planned beds, they can be assembled with just a small investment.

On Tobacco Road Farm in Lebanon, Connecticut (about an hour east of Hartford), organic market growers Bryan and Anita O'Hara have over an acre of low tunnels for extending fall vegetable production and growing a variety of baby and braising greens and other vegetables throughout the colder months. The low tunnels are removed in late spring to allow for easier field production. The O'Haras complement their low tunnels with two small 14' and 16' wide high tunnels used for seedling production.

The couple markets their mixed vegetables and maple syrup cooperatively with Bryan's father. Their stand always sells out at the two Saturday farmers' markets their family attends from early May through Thanksgiving. The nearby Willimantic Food Co-op, which just tripled its store area, is their other major outlet and has a standing order with them.

Several factors, including southern exposure and wind protection, help make low tunnels feasible for impressive season extension at Tobacco Road Farm. The low tunnels at the farm are situated on a sloping, southwest facing field. Conifer windbreaks mitigate the prevailing west wind. A third environmental advantage to this site is a large damned river the size of a small lake located beyond a grove of trees next to the field.

But this is not a snow-free environment. While most snowfall is light, the O'Haras may receive as much as 8" or 10" of snow at a time. And though snow usually melts in a few days, their low tunnels have been covered by snow for a month, without harmful effects on the plants inside. However, when the tunnels are covered in snow, harvest is impossible.

The O'Haras have been using these inexpensive tunnels for about 10 years at an annual cost of about 7.5 cents per square foot ($3,000/acre) to extend their growing and harvest season. At first, their goal was to push fall production later. Driven by strong customer demand for the good-tasting, cold weather-grown greens and their need for farm income, they just kept on expanding their off season production. Bryan said, "We realized that these plants are winter annuals. They have no disease and insect pests when we grow them out of season."

The seeding dates for their winter and spring low tunnel crops are astonishing late. They continue planting through the beginning of December and start up again in February. All these crops—which include lettuces, Asian greens, spinach, kales, Claytonia, scallions, beets, carrots, dandelions, parsley, and arugula—are direct seeded with an Earthway seeder. Normally, harvest continues until Christmas and then resumes in March. The mild winter of 2005-06 allowed them to harvest at intervals in January and February as well.

At Tobacco Road Farm, beds are standardized at 3' wide, separated by 8" wheel tracks. For this bed width, the wire hoops must be at least 80" long. The hoops are about 24" high at center. The minimum hoop size is 3/16" round stock. Either steel or galvanized will do. Wire hoops are spaced 2' to 2.5' apart. The tunnels are covered with two layers of plastic at frost, usually in early October. In March, the warming sun prompts the removal of the plastic film and its replacement with Agribon. This spun polyester row cover breathes and lets water pass through. Both the plastic and the fabric row cover are held down with up to a dozen 6 ml black plastic sand bags.

Bryan buys 20' lengths of steel wire at a local metal shop and has them chop it in thirds, precisely the length he needs. Bryan has used the same steel wire for over 10 years. Chafing from surface rust only occasionally causes rips in the Agribon row cover, while also helping to stick the cover onto the hoops. Galvanized steel is much more expensive.

For ease of operation, the beds are covered in 40' sections. Wind build up makes longer sections unmanageable,

and with the length of this low tunnel, two people working together can uncover a whole field in little time. Bryan uses two layers of cheap 1.5 mil construction grade plastic. A 200' length of this film will suffice for two 40' sections. To close the ends, 50' of plastic is needed to skin 40' long low tunnels. The ends are bunched up and pulled tight to create tension over the top of the hoops.

Bryan is an enthusiastic missionary for the environmental control provided by low tunnels. They prevent excess precipitation from damaging germination and ruining crops, and protect crops from wind and cold. Bryan has measured a 35°F gain on sunny days. The low tunnels should be vented if the outside temperature reaches about 70°F and opened to catch precipitation if excessively dry. In 2005, Bryan kept the beds uncovered until the extremely late first frost on October 21, a lapse he came to regret since 20" of rain that month broke all records. If the beds had been covered, the crops would not have been devastated and it would have been more possible to control chickweed with cultivation.

Irrigation is rarely required until later in winter. The plants seem to like it drier in winter, Bryan explained, noting two mechanisms that plants use to withstand cold temperatures: desiccation and mineralization of their sap to reduce their freezing point. These mechanisms make these crops extremely sweet-tasting in the winter.

In the central Connecticut climate, snow build up has not been a problem for the low tunnels. The hoops are pushed down by snow load, but pop up, pushing off the snow, as soon as the sun begins melting it. Snow accumulation on the wheel tracks insulates the low tunnels, provides a windbreak, and also holds down the row cover.

For several years, Bryan has been selecting Asian greens and arugula for cold hardiness. This breeding has yielded quick results, boosting winter survival from 10% to 100% in arugula just by collecting seed from planted that made it through the winter. For his first breeding experiments, Bryan seeded three adjacent beds of Mizuna, Tatsoi, and Miruba. He replanted the next year from the seed he harvested from the Mizuna mother plants which successfully over-wintered. Each year he collects seed from subsequent generations of plants interbred from the three cultivars that survive the winter. The hybrid seed selected from a large gene pool produces very vigorous plants with much greater cold tolerance. He can stagger seed production by altering when he harvests for salad mix.

Chickweed is the biggest weed problem in winter low tunnel production. Before they grew year round, the O'Haras used to tolerate chickweed in their fields over the winter so now they are grappling with a huge seed bank. Seeding crops very late in the fall allows late tillage, reducing chickweed germination, and the Asian greens sown on December 2 were their cleanest over-wintered crop.

At Tobacco Road Farm low tunnels have a variety of advantages:

- Low tunnels are very inexpensive and quick to install. Bryan estimated that two people could cover over an acre in two days.
- In the spring, low tunnels are more easily cooled than high tunnels to prevent bolting.
- Low tunnels are easily converted from plastic to cloth covers.
- Low tunnels allow farmers to manage water, protecting crops and soil from excess rain and wind. A slight slope allows water to run off the tunnels.
- Low tunnels allow farmers to grow without insect and disease pressure.
- Since low tunnels are closer to the earth, they provide more heat to the plants in the day. Bryan said they are 3° to 5°F warmer than ambient temperature on cold nights, similar to their high tunnels.
- Cold growing conditions enhance the taste of the crops.
- Low tunnels convert readily for regular summer production, allowing triple cropping.
- Soil preparation and other tractor operations can be carried out in the field prior to quick installation of the low tunnels.
- As they are easily removable, low tunnels reduce soil salt build up.

The O'Haras also recognize that low tunnels have the following disadvantages, some of which are common to high tunnels as well:

- The biggest issue is that low tunnels are more labor intensive. To hoe, harvest, or irrigate, the coverings must be removed.
- Low tunnels cannot be automated and require a lot of bending to manage the cover, causing worker discomfort.
- Low tunnels restrict access compared to high tunnels. One can't harvest on a cold, windy day.
- Cut lettuce grown under plastic film-covered low tunnels (or high tunnels) is very delicate and wilts quickly. This is one reason to convert to a fabric covering like Agribon.
- Low tunnels provide a perfect environment for chickweed, the ultimate winter weed.
- The plastic cover on low tunnels must be vented during warm sunny late fall and winter days.

(An earlier version of this profile appeared in "Growing for Market.")

Construction Tips

Hoop house construction can be as exacting or casual as you like. However, not paying attention to initial details can cost extra time in the long run, and the resulting structure may not look as nice or stand as long.

Two people with good construction skills can erect a 30' x 96' high tunnel in about a week. The 75 to 100 hour estimated completion time assumes that all materials are on site. Setting up the metal frame, installing baseboards and hipboards, roll-up sides, and building endwalls are included. Additional time will be required for site preparation, utility installation and covering the tunnel with polyethylene film.

Most manufacturers provide instruction manuals with the frame and technical support if needed. Some, however, are less helpful than others in their support so inquire before selecting a company. The most important step is to make certain that the site is square and uniformly pitched or level. If this is done carefully, the frame should install easily.

Instead of step-by-step instructions for constructing a high tunnel, here we offer tips to save you time and money. We hope these recommendations enable you to complete your project with less stress and more confidence.

Start with an adequate selection of tools to make the construction process a pleasant one. Tools to assemble include the following:

- level, level string, chalk line, and transit;
- long-handled mallet or sledge hammer for driving ground stakes;
- post-hole digger for endwall posts;
- cordless drill and drill bits (plus spares) for the various size fasteners you plan to use;
- good step ladder;
- socket set;
- drift punch or pipe wrench;
- miter saw or circular saw;
- speed square;
- hacksaw or saws-all;
- power cord; and
- tape measures (12', 25', and 100').

An experienced high tunnel builder advises: “a cordless drill (preferably one with ample batteries) will be your best friend for fastening those millions of quarter inch bolts and nuts.”

Batter Boards

It is important to set up batter boards at the start of high tunnel construction *(see Diagram 4 below)*. The small amount of extra time involved will be well-rewarded by the increased ease of construction. The use of these semi-permanent building markers is described at www.dulley.com/deck/deck01.shtml.

Batter boards define the corners and heights of the high tunnel. They allow you to erect the structure with confidence whenever you are ready. There is nothing worse than grabbing an hour here or there to work on a high tunnel only to find that someone bumped the stake and all your work is now out of line.

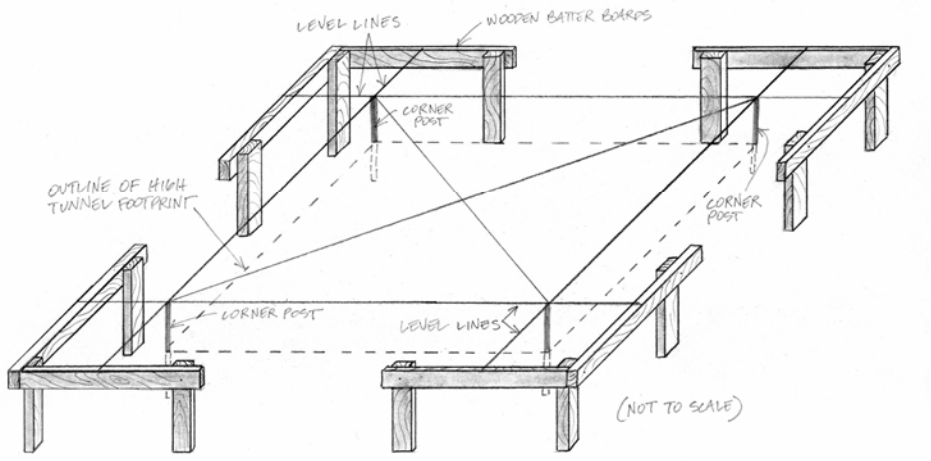
Ground Posts

As farmers, we are striving for a loose, well-structured soil in which to grow our plants. But we need a medium with the opposite characteristics to support a building. (If you have concerns about your site and its ability to support a high tunnel, check with a qualified professional.)

A high tunnel’s foundation is provided by ground posts, which are steel pipes partially buried in the ground. On rocky ground, in high wind areas, or where significant ground disturbance occurred during site preparation, a little additional support may be warranted. In these specific situations or for extra stability, a couple shovels of cement will effectively keep ground pins in place.

A sledgehammer is commonly used to drive in short ground posts. Most companies provide a protective piece

DIAGRAM 4. BATTER BOARDS AND CORNER POSTS

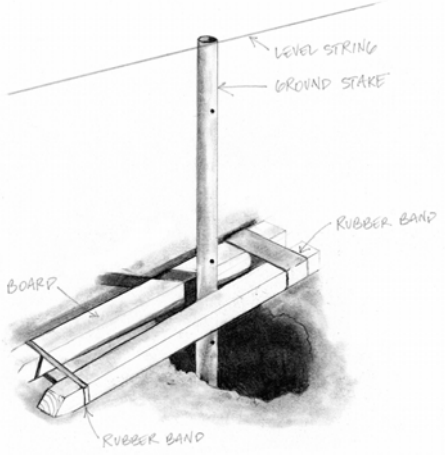


to put in the pipe to protect the end from being damaged or "doughnuting." For a taller structure with extended ground posts, John Biernbaum (who researches and teaches about high tunnels at Michigan State University) has found that a post or fence pounder works better.

The ground posts at the four corners should be solidly cemented in. For tunnels over 70' long, also cement in the intermediate ground posts in the middle of the long sides. Cement must be placed below the soil freeze zone, as the freezing action can force the ground pin up out of the ground. You may want to use caution when employing cement as this may move the structure into a 'permanent' classification.

Steve Moore suggests a good way to keep the ground posts in place so they don't pull out of the cement or slide down: pre-drill the ground posts within 2" or 3" of the bottom and insert a 4" to 6" piece of rebar.

The ground posts need to be in the right location and at the right height. A jig made with two old boards and some broccoli-type rubber bands or thin bungee cords will align the posts with the strings between the batter boards that outline the high tunnel. *(See diagram below.)* It will also keep the posts at the desired height. This simple device is removed once the cement hardens in 12 to 24 hours.



To ensure that the posts are placed at the correct height, use a transit, hose level, or laser level. Then take down the batter boards and run a high-strength nylon mason cord between the corner ground posts. Pull the string as tightly as you can to minimize droop over the long distance. Be careful; if a tight nylon string breaks, it can hurt someone as the end whips past.

The bows – and therefore the ground posts – of most high tunnels are spaced on 4', 5', or 6' centers. A wooden template with notches at 4' (or whatever the bow spacing is) eliminates the need for the time-consuming and awkward task of measuring from bow center to center. Ledgewood and Rimol provide their greenhouse customers with these spacers. They are also easy to make. John Biernbaum regards them as essential for construction.

Alternatively, Steve Moore recommends measuring from the same side of a post every time to attain an accurate center measurement. Taping the end of the measuring tape to the corner ground post is one simple way to do this. A level should be used to ensure the posts are vertical/plumb. A post level that has bubbles at 90 degree angles is useful because both directions can be seen at once.

Bows

Bows typically consist of two or three shorter pieces of metal tubing. Preassemble bows loosely. Do not tighten the bolts. This loose bow assembly will help in purlin installation. (Purlins are horizontal pieces typically made of pipe that is a smaller diameter on one end (swedged) to fit inside the next pipe.)

Historically, pike poles were used to push up large sections of timber framing for barns. Pike poles also have a place in erecting high tunnels.

Raising a heavy bow on a wide tunnel (20' or wider) is best accomplished with at least three people. One person stands at each leg of the bow, and a third pushes the bow up in the air with a pike pole. This is heavy work. Each bow will need to be picked up and wiggled onto the spline/ground posts. Use one or two pike poles to keep the bow assembly from falling while the crew wiggles it onto the ground posts.

Purlins

Purlins help stabilize the high tunnel. They are bolted to the bows, along the length of the structure. Typically a 30' tunnel will have five purlins, including the ridge pole.

The purlins can be attached once the bows are loosely assembled and in place. A platform is much safer than ladders and saves a tremendous amount of time and energy. Use a hay wagon, truck bed, or scaffolding, especially if you can pull it along as you go!

A drift punch or pipe wrench can be used to help align bow and purlin holes. As you attach the purlins, tighten all bow bolts, except those that connect the bow to the ground pin. Finally, when you are at the end bow, with all the purlins in place, you are ready to "plumb" the gable end to straighten the entire bow/purlin assembly.

Attach one string with a plumb bob to the top point of the outside edge of the last bow, and a second ground string to the outside edge of the bottom bow. Allow the plumb bob string to come within 1/8" of the ground string.

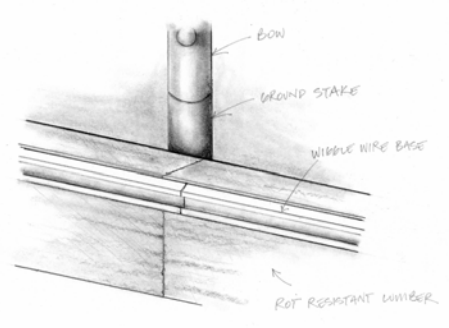
A good way to adjust and hold the high tunnel plumb is to attach a come-along to a large immovable object like a tree or truck and then attach a rope or chain from the come-along up to the bow. A come-along's ratcheting mechanism and its steel cable allow for quick and precise alignment of the tunnel. Now you can tighten all

remaining bolts and install the wind braces.

Baseboards

The baseboards sit on the ground along the sides of a high tunnel. They are bolted to the ground posts. Use 1.5" x 8" lumber for baseboards.

Consider sourcing your lumber from local family-owned and operated sawmills. Often boards from these mills are sawn several inches longer than their designated length, rather than being trimmed down to an exact, even foot measure. This extra length will allow you to cut the ends at a 45 degree angle for joining together at the bows with a 1/4" machine bolt *(see diagram below).*



Use a long 1/4" bit to drill out the holes for the bolt through the wood from the inside of the high tunnel. This added length is helpful when attaching framing to bows.

Machine bolts are superior to carriage bolts for attaching the poly hold-down strips to the baseboard. Carriage bolts are often used for this purpose, but they rust fast. When the baseboard needs to be replaced, sometimes the nuts are stuck in place and won't turn. With a wrench on either side of the nut and bolt, the machine bolts will break off much faster and easier than hack sawing carriage bolts, which only turn in the wood.

While bolts may be better for attaching the base boards and hip boards to the bows, galvanized pipe straps can also do a good job, as long as the pipe strap is also tek-screwed to the bow. Ted Blomgren recommends using a washer on the wood screw.

The frame will be complete after the hip board (2" x 6" lumber) along with "poly lock" or "wiggle wire" base is attached to the bows approximately 5' or 6' off the ground. (Poly lock is the trade name for an extrusion for attaching the polyethylene film to the structure. It serves the same purpose as wiggle wire.) This will serve as the point of attachment for the plastic covering.

The hip board should be inspected at each change of polyethylene to make sure it will be sound for another four or five years. Farmers should be aware of rot and ready to replace the baseboard as necessary; the plastic need not be removed to do so.

Gable Ends

Doors should be large enough for ventilation and easy access. They can span even the full width of the high tunnel. To maximize airflow and accessibility, some farmers construct removable end walls. A smaller, personal door that opens inward makes a convenient winter passage.

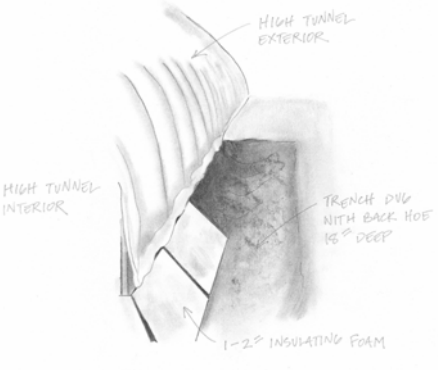
Unless the high tunnel will have very wide doors, some tasks such as adding compost, tilling the soil, and installing utilities are best accomplished before the gable ends are closed in and access is restricted.

Gable end framing can be done with steel or wood. If using wood, either select one of the rot-resistant species recommended for the baseboards *(see materials section)* or be prepared to replace the wood as needed. Steve Moore uses rough sawn 2 x 4s to frame the gable end. When the wood rots right at the soil line where moisture and air meet, rather than take apart the whole assembly, he just pounds in a U-shaped steel fence post and lag or machine bolts it to the post that had rotted off. "This buys me a good many more years service," he says.

If you use a rigid gable-end covering, such as polycarbonate, the outside of the baseboard will need to be flush with the outside of the bow. To make it flush, attach an 8" piece of universal corner (a thin-walled piece of angle iron with multiple holes for bolting) with the same bolts that hold the side baseboard.

Insulation

In cold climates, insulation can make a significant difference in the performance of high tunnels. In Zone 6, burying 1" thick by 2' wide rigid foam (i.e. polystyrene) isolates frozen ground from growing areas. The thickness and depth of insulation should be modified according to your climatic zone. This foam should be buried at an angle to gain more benefit from the thermal mass of the earth. The angled placement also makes installation easier and allows space for the cement support at the bottom of the ground pin *(see diagram below).* Insulation can also be used in pathways and along the lower portion of the sidewalls.



Hiring Out Construction

For some farmers, hiring an experienced crew to do the installation may be the best option. The estimated labor cost for basic high tunnel construction used to be fifty cents to one dollar per square foot. However, due to inflation, the labor bill for high tunnel construction in previous years may not be relevant for estimating costs under current conditions. Like any construction project today, expect skilled contractors to be expensive.

Bending Your Own Frames

Rather than purchasing a hoop house kit, some farmers choose to bend their own. A good role model for this activity is Ed Person of Ledgewood Greenhouse. This New Hampshire farmer went from bending frames for his own use to developing a substantial independent business that sells and delivers high tunnel frames throughout the Northeast.

For savvy shoppers, fabricating a high tunnel steel frame can save money. It also allows farmers to realize a better design idea, satisfy unique needs, or add onto an existing high tunnel.

Ted and Jan Blomgren bent several Gothic arch high tunnel frames for their farm. Three people worked for about the equivalent of one week fabricating the jigs and bending and drilling the component parts for three and a half 30' x 96' high tunnels with trusses.

At the time, they were able to make their own high tunnel frames for a third of the cost of a kit, thanks to a farmer friend's tip about a supplier of economically priced steel. Ted cautions though that purchasing steel from a local chain link fence supplier might actually cost more than buying a kit with pre-bent, pre-drilled steel.

The Blomgrens' bows consisted of two long side pieces with a shorter, smaller diameter piece at the ridge. In all, they used three sizes of steel pipe—1.9", 1.6" and 1.3" diameter for bow, small ridge bow, and purlins, respectively—to fabricate all the high tunnel components including trusses. The only new tools they needed were a chop saw and drill press outfitted for cutting and drilling steel. After four years, there is no rust at the bends and the galvanized coating has not popped off.

They built the two jigs needed for bending the steel for the bows by replicating a bow they had removed from their existing high tunnel. To bend the steel, they placed a jig, made of two-ply 3/4" plywood and lumber, on the level cement floor of their garage, braced against its foundation. For the easier, shallow bend, they were able to use their sedan with a steel cable attached to the trailer hitch. The more acute portion of the bow required the weight and traction of their heavy John Deere tractor. To compensate for the springback in steel, they bent it until it fit a pattern they had outlined on the floor.

Bending the bows for a high tunnel can be a simpler process. For example, Thomas Christenfeld, a neighbor of the Blomgrens, bent the bows for his Quonset-style greenhouse using a silo as a jig. He stuck one end on one of the hoop bolts that holds the concrete panels of the silo together and bent the other end around the silo. Two people are needed to get a good enough bend in the pipe and that it probably only works for a single piece hoop. Thomas notes, "You cannot get any real bend in the ends of the pipe so two pieces stuck together leaves a flat part on top of the hoop house, which is far from ideal in a snowy climate."

Another Way to Bend Your Own

Kevin Loth, who is contractor as well as a farmer, has fabricated his family's 20' x 200' Quonset-style high tunnels near Lincoln, Nebraska. The Loths have two heated greenhouses and two year round high tunnels. By bending his own bows, he was able to get twice as much ground under cover than if he purchased kits. His calculation included what he paid a helper but not his own time. He said if you don't drill the bows, you could probably bend them in a day, though set up might take a couple of days.

With a borrowed pipe bender, he made bows out of the 15 gauge metal pipe used as a chain-link fence top rail. He saved considerably on the pipe by purchasing it by the bundle of 91 pipes. Because the pipe comes in 21' lengths, he had to swedge together one and a half lengths for each bow. While a swedging tool can be expensive, often when you buy fencing steel, one end comes already swedged.

His finished tunnels are Quonset-shaped, 10' high at the peak. Their bows are 4' on center, and they have two purlins but no trusses.

Kevin has attached the purlins and bows in several ways. Holes should be drilled prior to bending the bows. For the less technically adept, purlin clamp connectors (available from greenhouse suppliers) or pipe clamps (from plumbing supply outfits) preclude the need to drill holes for the bolts attaching the purlins. Getting these holes to line up properly can be difficult. Moreover, the very act of drilling holes weakens the steel.

While the purlin connectors are aluminum, Kevin dismisses concern about mixing metals as the tunnel's steel is galvanized. He thinks this is less of an issue than drilling holes as that action exposes ungalvanized steel and weakens the structural pieces. Also he noted that the ends of the bows are in contact with corrosive cement and soil acids.

Covering a High Tunnel

Farmers employ several methods for getting the unwieldy expanse of polyethylene film over the top of large hoop house structures and evenly attached. The size of your crew helps determine which methods are most feasible. The most important rule of thumb is never attempt to cover a tunnel on a windy day.

Covering a large (i.e., 30' x 96') high tunnel with a single layer of poly should take four or five people two or three hours. There is a learning curve so the first few times may take longer.

Method A: Pull over the end.
For this method, four or five people and a center-folded roll of polyethylene are required. (You can order your polyethylene folded in several ways.)

The first step is unrolling the plastic. To do this, set up a pair of cinderblocks a few feet further apart than the length of the roll of polyethylene. For a 12' tube, set the blocks about 14' apart. Then put a pipe in the tube. Make cardboard washers about 1' square to put on the ends of the pipe. The washers serve to protect the ends of the rolled up polyethylene from abrasion against the cinderblocks when you unroll it. This set up should allow the plastic to freely unroll.

The next step, getting the plastic over the tunnel, requires five people. One person is stationed on a ladder at a gable end of the high tunnel. Wearing a hooded sweatshirt is recommended to avoid plastic rubbing and to counteract the static electric generated by moving the plastic film over head. The center of the end of the poly is passed to the person on the ladder. The film unrolls as it is pulled up the ladder. Two people on the ground hold the corners and walk along side the tunnel as the plastic is unfurled. Meanwhile the person on the ladder does a sort of butterfly swimming stroke, bringing the plastic overhead so that it clears the peak without getting caught.

The two people walking along the sides can have an exceedingly long way to pull the plastic. When they reach the middle of a long tunnel, two more people standing at the original gable end should assist pulling the plastic along. These additional people also help keep the plastic from becoming a sail if a sudden gust of wind comes along.

After the whole tunnel has been covered, it's time to even out the plastic. The selvage edge must be even for the entire length of the tunnel and should be 12" or longer. You don't want the edge to run out!

If you are putting a second covering on, just tack it on the first layer using just a couple strategically placed poly fasteners (i.e., wiggle wire) and repeat the process with the second covering. Otherwise, proceed to the next step.

Once you are satisfied that the plastic is even on the edge, temporarily secure the plastic in place at three or four points on each side. The most common method for securing the plastic is wiggle wire inserted into a U channel. An alternative assembly is homemade—wood attached with drywall screws every 6" to 8".

Now you are ready to fully secure the single or double layer of plastic. The person on the ladder inserts wiggle wire from the top down on one of the gable ends. Next the plastic film at the other gable end should be pulled and that plastic "tacked" down. Once one gable-end plastic is permanently attached and the other gable end has been "tacked" in place (with a short wiggle wire), one side can be attached for a distance of about three bows. Remember to keep a constant selvage (waste) edge. Another person (or two) starts on the opposite side of the first group and both groups attach side plastic down to the end and finish the gable end. The reason for the staggered start and attachment is to avoid see-sawing the plastic side to side. The lead attachers must always keep the selvage edge the same while the other side pulls the plastic to match.

Getting all of the wrinkles out is not important if you are going to inflate. It is important not to pull the poly film so tight that the wiggle wire in the U channel perforates the new plastic.

A variation on the pull-over-the-end method of covering a high tunnel is used by the Kilpatrick family. They set up the plastic on scaffolding at one end of the tunnel as described above. "Make sure the scaffolding is above the peak of the structure. While one person pulls the plastic down the length of the high tunnel, the others assist from the ground." Philip and Michael Kilpatrick have found that for work on the purlins, scaffolding mounted on a cart is far more convenient than using a ladder.

Method B: Ridge-roll.
This is one of the two ways that the Blomgrens cover their tunnels. (The other way is described in Method C.) Both methods involve climbing up the high tunnel and thus entail danger. Use these methods at your own risk.

Covering a high tunnel with a lean crew (four people) necessitates a different method. Once again, make sure to obtain greenhouse plastic with its fold down the center so it will unfurl properly.

In this technique two people carry the entire roll of poly up to the top of the high tunnel. A bucket loader is handy for this purpose. Before climbing up, they insert a pipe into the cardboard tube to assist in unrolling it. With the roll sitting on the top purlin, they temporarily fasten it on the gable end of the tunnel. Then they proceed to walk it down the tunnel, making use

of the side purlins, walking the roll along as they go. By the time the pair has walked halfway down the tunnel, the plastic will have begun unfurling, with half falling down one side and half down the other. (This unrolling procedure will go much more quickly if the high tunnel is designed so that the ridge purlin is situated on top of the bow. This is an atypical purlin placement and is only advisable for tunnels that will never be covered with a double, inflated layer of poly.)

Meanwhile the two other people, who are on the ground, are starting to tentatively connect the poly to the hip board just above the roll up sides.

After the plastic has been unrolled along the entire length of the tunnel, the two people who have been walking the ridge with the roll of poly temporarily connect the poly with wiggle wire at the top of the second gable end. They then climb down and join the two folks on the ground. With two people on each side of the tunnel, they square up the plastic, and then begin attaching the plastic along the top of the roll up sides. With the two teams working on opposite sides of the tunnel, they start at one end, and work toward the other end.

They then finish the gable ends, taking up the slack and smoothing out wrinkles, before permanently attaching it there. They trim off the excess plastic at the gable ends so it doesn't flap in the wind. To complete the covering, the roll up sides must be attached.

Method C: Over the side.
Like the previous method, this covering procedure used by the Blomgrens has safety and liability issues. As an alternative to climbing over the tunnel frame, Steve Moore suggests attaching grommets to the plastic and using ropes to pull it over the structure.

For a big tunnel (30' x 96' or 150'), at least eight people are needed for this method. Start by unrolling the plastic (without unfolding it) along the side of the high tunnel. If there is a risk of the slightest wind, it is best to be on the windward side of the tunnel.

After the plastic has been unrolled, people station themselves at regular intervals along the tunnel. They each take hold of what will become the far edge of the poly. Pulling this edge, they climb up and over the tunnel. With enough people, the weight of the poly is distributed and not burdensome to anyone.

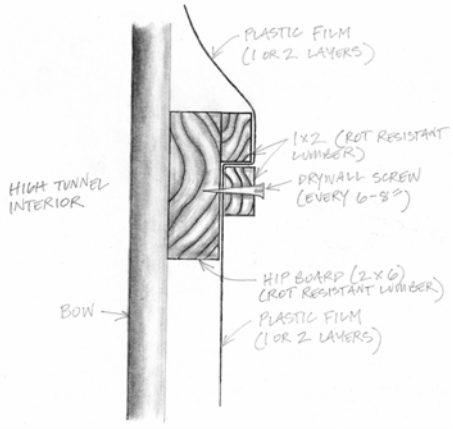
Once the plastic is over the top of the structure, it is squared up, and then temporarily fastened to the gable ends. They then proceed as in the above description, with teams starting from opposite sides of one end and both working toward the far end.

There is an alternative to climbing up and over the greenhouse. Ropes may be attached to the plastic along its side. Clips available from greenhouse suppliers can be used to secure the rope to the plastic. Alternatively, wrap tennis balls in the plastic and use them to help fasten the rope. Toss the ropes over the tunnel structure and, once on the other side, pull the plastic over.

Tips for Attaching the Plastic

Single poly can be difficult to keep on a structure because there is no tension from an inflation fan to reduce flapping. Steve Moore has used wide poly strapping placed between every other bow and attached to the baseboard to keep the cover in place. This increases the longevity of the plastic film, and also reduces a farmer's worry about losing the plastic on the tunnels (and sleep) on windy nights.

If you choose to use wooden batten boards to fasten the plastic to the hip board, you would be wise to use a pair of batten boards one above the other with the plastic outside of the top one and behind the bottom one. This more effectively locks the poly in place. *(See diagram below.)*



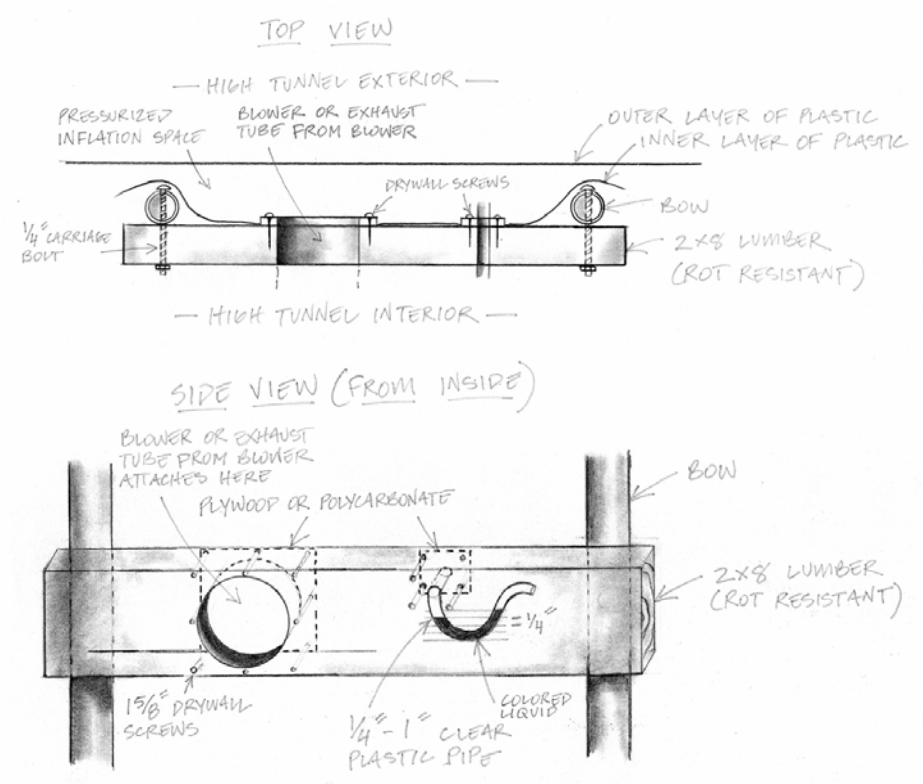
After you have to undo rusty screws or other failing attachments to remove old poly, you will probably come to believe that wiggle wire is a bargain at a $1 per foot. When attaching new poly with wiggle wire, don't pull the poly too tight (or over inflate). The wiggle wire will actually cut perforations (corresponding to the wiggle wire) in the new cover if there is too much tension. This applies to double layers of poly, too.

When attaching plastic to battens (thin boards less than 1/2" x 1-1/2"), use double headed nails—rather than regular nails—for easier removal. Galvanized screws are another option.

Getting the Right Pressure on Your Inflation

Correct pressure ensures a balance between over and under inflation. By providing sufficient tightness of the plastic, flapping is minimized. If the plastic is stretched too tightly, light transmission is reduced. Simply put, correct pressure increases the life of the plastic and its ability to transmit light.

A manometer is an instrument used to measure the pressure of a gas. For high tunnels with a double poly layer, it is useful for determining the proper inflation pressure. Steve Moore makes his own homemade manometer using this simple procedure.



On the inside of the tunnel, attach a 2" x 8" (or wider) board with carriage bolts to two of the bows at a 4' to 6' height. (This board can be used to mount the inflation fan as well.) After covering the high tunnel with the first layer of poly, a 4" to 6" square piece of polycarbonate is attached with drywall screws to the wood before the tunnel is covered with a second layer of poly.

From the interior of the tunnel, drill a hole through the wood, the inside layer of plastic and the small piece of rigid material. From the inside, push a clear flexible plastic tube (available by the foot at most hardware store) into the wood, allowing the tube free access to the air between the layers. The tube's internal diameter can be from 3/4" to 1". Caulk around the tube so that it is airtight to prevent leaks.

Let the tube form a "U" with one of the top legs of the U going through the wood. Attach the other top of the U tube to the board and fill the bottom of the U with a colored liquid (blue washer fluid or colored water). Mark level horizontal lines ¼ of an inch apart on the board next to the U portion of the clear tube. If the interior air level of the U is ¼ inch higher than the inflation side of the U, then the pressure is about right. The liquid level on the side of the U that is attached to the board should be 1/4 " lower than the side of the U that is open to the inside of the tunnel.

Adjust the pressure by using a damper on the intake of the inflation fan. You can make a damper with a flat piece of metal, like an old can lid (taped to keep from cutting yourself). Insert a screw through the top edge of the metal lid. Attach it tightly enough to the intake of the inflation fan that it will stay in place at various degrees of opening.

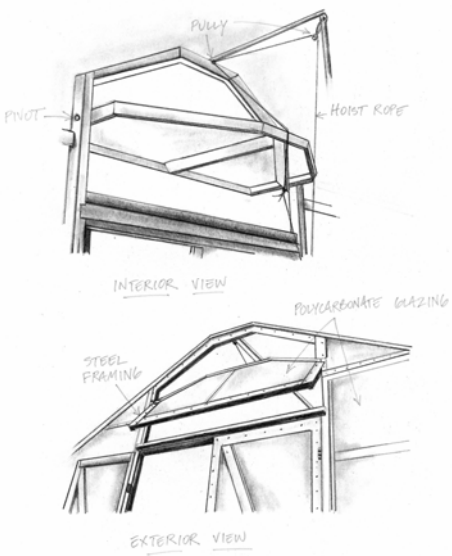
Steve has used solar power to run the inflation fan and his monitoring equipment.

Environmental Management

Ventilation and Cooling

Venting to reduce humidity is more important than keeping the tunnel closed to boost the temperature. The sacrifice of a few degrees in favor of lower humidity will contribute to overall plant health.

High tunnel ventilation is usually accomplished by the passive movement of air through the structure. The air movement through tunnels occurs through roll-up sides, gable-end doors and vents, ridge vents, and removable end walls. *(See below.)*



For growers who also work off the farm, an automated vent is essential. Motorized louvers are readily available, and probably pay for themselves relatively quickly, but solar openers are good alternatives to motors.

The height of roll-up sides should be considered when selecting or designing a high tunnel. The higher the sidewall, the greater the potential air movement through a tunnel. Sidewall height depends in part upon the design of the tunnel. For instance, straight sidewalls—the norm for Gothic structures—allow for higher roll-up sides than curved walls. Longer ground pipes or leg extensions on the bows of Quonset tunnels add height to sidewalls. Gothic tunnels also allow for bigger gable-end vents over the door than Quonset tunnels. Caterpillar tunnels and multi-bay tunnels like Haygroves provide superior venting, since entire sidewalls can be pushed up to allow air passage in both structures.

To prevent tender plants from being blasted with cold air when roll-up sides are vented, some growers are installing a low protective sidewall 12 to 18" above ground level. Poly film, clear acrylic, and polycarbonate have all been used for this purpose. Roll-down side curtains offer another solution.

Large gable-end vents and doors and removable end doors help maximize venting with no energy cost. Retrofitting is feasible, but planning ahead for optimal ventilation during the design phase is best.

Ryan Voiland at Red Fire Farm near Amherst, Massachusetts, purchased a 35' x 120' Harnois greenhouse kit because it seemed the best option for ridge venting. The roof comes to a higher peak in his model than in others. A 24" wide flat piece of plastic at the ridge moves to open the vent. The opening mechanism is powered by a small motor that is activated by a thermostat.

The frame with the ridge vent costs considerably more than a frame without one. Since the frame was also more complicated, Ryan hired a greenhouse builder to erect it. To access the ridge vent, his tunnel has a catwalk on top of the frame. Covering the ridge-vented tunnel with plastic is challenging and follows a different procedure.

Ridge Vents

In ridge-vent systems, cooler air enters the high tunnel through roll-up sides or gable-end openings, and hotter air rises and exits through the ridge vent. These systems work very well, but few high tunnel growers seem to use them, as they are more expensive to purchase and install. Ridge vents can be manually or mechanically operated. Some growers have even constructed their own ridge vents.

An alternative to an expensive full-length ridge vent is a series of small roof vents which act as chimneys to vent out hot air. For several years, Ken-Bar has made an inexpensive roof-installed vent for high tunnels that is available from Farm Tek for a little over $200. These vents have an actual 30" x 14" opening and should be installed every 20' to 25'. A $50 solar vent opener eliminates the need for a noisy motor and an electrical hookup. *(See "Greenhouse Supplies" on page xx.)*

Although Ryan is satisfied with the venting of his large tomato high tunnel, he said he would not opt for a ridge-vented structure again due to the costs and complications of construction. He believes that an exhaust fan could adequately serve the same function.

Fans

Multi-bay and walk-in tunnels can be vented very effectively, but the narrower openings in more traditional high tunnels sometimes constrict airflow. While passive venting is usually sufficient in well-designed high tunnels, several circumstances prompt some high tunnel growers to turn to fans to cool their tunnels, reduce humidity, and improve air circulation.

Photovoltaic Inflation Systems

By Steve Moore

Most traditional hoop houses or high tunnels have only one layer of poly film as a covering, so no blower fan is used. But thermal performance is far better in dual covered structures.

Heated greenhouses typically use two layers of poly film and require a blower. Inflation has two functions. First, it creates a dead air space for insulation. Secondly, it provides turgor to the covering. Keeping the plastic at the right tautness prevents stretching which reduces light transmission. It also prevents tearing.

There are a variety of energy sources to power an inflation fan or blower. For example, Amish farmers sometimes run inflation fans on compressed air to keep within the bounds of their faith. Otherwise, most applications require electricity.

However, not infrequently, high tunnels are located at a distance from grid-connected electrical service. Hook-up can be costly. The alternative we have used is solar photovoltaics—electric power from the sun. Our independent solar power system has worked well for many years.

We used a 32-watt Unisolar flat photovoltaic panel ($210), a Morningstar charge controller, two 6-volt golf cart batteries ($70 - $80 each) and a 12-volt blower fan. With renewable energy, it is cheaper to reduce energy demand than to produce more energy. We were lucky in finding such a fan through a military surplus outlet. This 4-watt blower fan ($20 when available -- see resources) has a very low amperage draw.

The rest of the system is built around the electric demand, in this case, the blower. The blower runs 24/7 so backup batteries are required for nighttime and long stretches of cloudy days. More northerly locations with shorter winter days may require a bigger solar panel and more battery storage capacity.

The two 6-volt batteries are wired in a series resulting in a 12-volt current which is compatible with the charge controller's needs and the solar panel output. In southeast Pennsylvania, the 32-watt solar panel was sufficient to keep the batteries charged for our long-term storage needs (times of little or no sun) and to power the blower and some monitoring equipment. We used a rather expensive charge controller so we could build on it for further expansion of the solar system. Otherwise, several small and inexpensive models ($35 to $100) would be more than adequate.

It is important to protect the batteries from cold. We all have experienced how cold reduces battery efficiency, when we try to start our car on very cold days. With this concern in mind, we chose to place them in a box below grade in the ground in the high tunnel where the earth's constant temperature moderates the cold. We also wanted to get them out from under foot and reduce the chance of spilling or puncturing the cases and releasing battery acid.

You must ventilate your battery box as explosive hydrogen can be a byproduct of battery charge and discharge cycling. We do this with a few holes in the plywood lid. By sizing it big enough, we get double duty out of our battery box. It also functions as an irrigation distribution box to add or change drip tape manifolds and other needs.

The production of trellised summer crops such as indeterminant tomatoes and cucumbers with lots of foliage can reduce air movement. Stagnant masses of humid air result in greater disease incidence. To avoid potential crop loss, it is not surprising that some growers opt for fans.

For winter production, when roll-up sides are buttoned down and doors firmly latched, gable-end vents may be too small to do the job. In this situation, an exhaust fan mounted high at one gable end coupled with a louvered vent at the other can help remove hot air and free moisture and reduce relative humidity in the structure. The louvered opening is controlled with a motor and thermostat.

In addition to an exhaust fan, Slack Hollow Farm uses four small fans hung from purlins to move air in a circular pattern in the 30' x 120' high tunnel. Commonly used in greenhouses, these horizontal airflow (HAF) fans create a gentle air current that moves and mixes air.

The Zemelskys had four HAF fans installed in each of their four 30' x 96'. high tunnels for a cost of $330 per tunnel, including the wiring. In the summer, the added air flow benefits their mostly heirloom tomato crop. However, for winter greens production they do not run these fans. The Zemelskys also use a gable-end exhaust fan in four of their five high tunnels.

Heat stress

Heat stress can be a problem for plants growing in high tunnels that are inadequately vented. When leaf surface temperatures get too hot, photosynthesis and other metabolic activities shut down. Plants close their stomata and stop transpiring. If overheating is allowed to continue, plants will grow poorly, and may eventually die.

A high tunnel full of plants will stay much cooler than an empty one. Transpiring plants release water into the air producing natural evaporative cooling. This is also why misters work well to lower the temperature and why trees, in addition to providing shade, cool down a city street.

Shade cloth is commonly used by greenhouse growers to reduce the interior temperature of the structure. But shade cloth has less applicability to high tunnel growing. In the Northeast, for many summer crops it will reduce light availability too greatly, resulting in poor overall growth and leggy plants.

Shade cloth does make sense for certain species of cut flowers in high tunnels. In southern Pennsylvania, the Cramers effectively use shade cloth in one bay of their Haygrove high tunnel to grow cool-loving (but long-season) lisianthus. This material moderates high summer temperatures and reduces light diffusion, producing the elongated stems required by the market.

Heating

High tunnels are normally defined as unheated greenhouses. Their primary sources of heat are solar energy and the ambient heat of the earth. Farmers don't use high tunnels to grow warm season crops significantly out of season; instead, they use them to extend the normal season by a period of several weeks. With the additional protection of internal row covers, adequate growing conditions for cold weather crops can be attained, even during the winter months.

For warm season crops such as tomatoes and cucumbers, a standby heating unit can be brought into a high

In-Ground Radiant Heat

In-ground, radiant heating tends to be a less energy-intensive approach than air heating for any structure, whether it is a building, greenhouse, or high tunnel. While relatively costly to install, in-ground systems, which circulate a heated fluid, consume less fuel than heating air, reducing fuel consumption and costs over time. Heating the root-zone stimulates seed germination and root development. In a radiant heating system, a water-antifreeze mixture is heated and circulated with small pumps through polyethylene tubing buried in the ground.

Slack Hollow Farm had been growing year-round in a high tunnel that had neither artificial heat nor electricity. But in their new 30' x 120' high tunnel, Seth Jacobs and Martha Johnson (with the assistance of a plumber) installed a radiant heating system that uses standard, off-the-shelf technology. Seth buried PEX tubing 18" deep, in rows 12" apart, using about a dozen 300' loops for the 30' x 120' tunnel. (Each loop consists of an outgoing and return stretch of tubing.) A 1:1 propylene glycol/water mixture, heated by an oil-fired hot water heater, circulates in the tubing. The heat spreads upward and outward in the soil at a 45-degree angle above the tubing. Once the heat is turned on, it takes about 10 to 12 hours to heat the soil 6" below the surface.

In designing their heating system, they were concerned that the antifreeze mixture circulating in the buried PEX tubing would be too hot for their crops. As a protective measure, they designed their system with all the "bells and whistles," including dampening valves and return-flow mixing. These added features have proven unnecessary in their application in part because the heater itself can be turned down to 110°F.

For the first winter (2005-06), they chose 47°F as the target soil temperature at a 6" depth. Under the row covers at night, the lowest air temperature was 27°F. It took a single tank of oil (275 gallons, costing $500) to maintain this soil temperature. With the onset of longer days in mid-February, they were able to stop burning oil for the rest of the winter (even though temperatures were cold). They found that the soil 6" down could gain 5°F on a sunny day.

In 2005, before the heating system had been installed, they grew tomatoes in their high tunnel without heat. They warmed the soil to 70°F for their spring 2006 tomato crop, consuming three-quarters of a tank of oil in several weeks during that cold spring. In both years they started wholesaling tomatoes around July 11.

With just one year of experience with their in-ground heating system, it is too early for Seth and Martha to draw conclusions about the economic feasibility of this application. In order to cut fuel requirements, they plan to insulate the soil around the tunnel's perimeter to a depth of at least 18". The temperature they will eventually choose for soil temperature in mid-spring for summer tomato production is still in question; they hope next year's trials will help them come to an answer.

tunnel as a temporary safeguard against extreme cold. But when growers install a permanent heating system, they begin to transform their high tunnels into something more akin to a greenhouse.

Nonetheless, farmers are constantly experimenting, and there is much to be learned from their attempts to create superior and cost-efficient growing conditions. While the pros and cons of conventional greenhouse heating systems are beyond the purview of this manual, one example of the use of in-ground heat is presented on page 50. Such a system has applications for growers who wish to minimally heat the soil in their structures just enough to prevent freezing.

Relative Humidity and Temperatures in a High Tunnel

Water condenses on the inside surface of a high tunnel or greenhouse cover when the outside temperature drops below the dew point. Free moisture in the air changes to a liquid state, the same way that dew is formed. When this condensation drips, it can damage plants and promote disease. Droplets of water on the plastic film reflect light away from the tunnel.

High relative humidity increases condensation. Evapotranspiration by plants contributes to the humidity level. Ventilation or heating can reduce moisture levels in the air.

High tunnel temperatures can be measured for the air, soil, or plants. Ventilation directly influences air temperature. Plant metabolism and growth processes affect plant temperature. The intensity of solar radiation affects the temperature of the first inch or two of the soil, but soil temperatures at greater depths are constant. Plant scorching may be influenced more by the intensity of solar radiation than by air temperature.

Adapted from Film Facts, www.bpiagri.com/hort-luminance.htm

Interior Row Covers

Floating row covers are commonly used to further protect plants from cold weather within high tunnels. They are either laid directly over plants or suspended over wire or pipe hoops in the form of low tunnels. Some farmers use plastic film to create tunnels within tunnels. This is a good use for old greenhouse film, as long as it is not so degraded as to prevent adequate light transmission. But plastic, whether new or used, traps moisture and overheats the enclosed space more readily than fabric row covers, and therefore must be opened or ventilated daily.

Alternatively, spun-bonded synthetic fabrics may be used. These include Remay, Typar, Agribon, Agrofabric, and Covertan. These row covers come in a various sizes and weights. Weights range from 0.5 to 2 ounces per square yard. Heavier materials cost more and are less apt to tear. Some are even rip-stop reinforced. The less the fabrics weigh the less cold protection they offer, but the more light they transmit. Because of this trade-off, the jury is out regarding the best weight row cover to choose under different conditions.

In Maine, Eliot Coleman prefers lighter weight materials as they allow more light to penetrate and warm the soil during the day than heavier row covers which provide a few more degrees of frost protection. He does not want to have to open and close inner covers daily. In contrast, while farming in Pennsylvania, Steve Moore used the heaviest weight fabrics for winter high tunnel production. He appreciates its increased insulating ability and durability and has come up with several streamlined systems for moving this material.

In Connecticut, the Zemelskys have used light- and mid-weight spun polyester row cover to assist the crop in germination and protect their hardy greens for winter production. Andy Jones, in Burlington, Vermont, typically covers his winter greens with a single layer of mid-weight row cover, though on occasion he adds a second layer when "super cold" conditions are expected. At Slack Hollow Farm in upstate New York, as many as three or four layers of a medium-weight row cover protect spinach and other greens in the dead of the winter.

At Slack Hollow, the covers are usually removed during the day. Seth Jacobs explains that, in order to take full advantage of solar gain, the ground needs to be exposed to incoming sunlight so it warms up the groundmass, and then insulated from the cold air at night. This concentrates the stored heat from the sun in the ground but eliminates the small layer of air under the cover. "On bitter cold, very cloudy days we might leave some or all of the covers on during the day, but we feel we should uncover whenever possible for maximum light on the plants, and heat gain in the soil," he said.

Steve Moore follows the same logic as Seth Jacobs for row cover management. On warm, sunny days, he rolls back the covers, while on cold and cloudy days he tends to leave the covers on. However when there is a string of two or more cloudy days, he finds it important to vent on "the best days" as air movement helps prevent and control disease.

In contrast, at the Intervale Community Farm in Vermont, Andy Jones explained that their row cover management is less intensive. “We wait to put them on until fairly late (around late November), but only plan to remove them at harvest or for other chores.”

In a class of its own is Tufbell, one of the heaviest, longest-lasting row cover materials on the market. Made of polyvinyl alcohol, its characteristics are more conducive to winter horticulture than the more common spun polyester. It increases air and soil temperature by 5 to10°F and leaf temperature by 2 to 6°F, yet does not overheat in 90°F weather. It allows 92 to 95% light transmission. Only minimally degraded by sunlight and reinforced against rips, it lasts at least five years or longer if protected in storage from mice and other nest builders. It can also be sewn and washed. However, at 22.5 cents per square foot, it costs more than twelve times as much as Argibon 19 (which costs 1.6 cents per square foot).

Over a period of several years, Steve Moore experimented with a variety of materials in two different configurations, using them as inner grow tunnels on 5' wide beds and also as a 14' wide covering (half the tunnel’s width). He tested the performance of used plastic (greenhouse film), Agribond products, Typar, Agribell, Low-e (1/4 inch foil faced bubble wrap), thermal curtain material, Aluminet, and several others.

He found that used plastic was almost as good as very costly alternatives in terms of thermal protection and heat retention. In fact, he concluded that it is the most economical and environmental choice. He also found that covering half of the high tunnel (14' width in a 30' house) performed better than covering one 5' bed at a time, regardless of the materials used. The tunnels within a tunnel averaged approximately 18°F warmer than outside temperatures. However, the temperature difference for the five coldest nights was about 26°F. “This is significant,” said Steve. “We want the most protection on the coldest nights.”

Steve was puzzled by some of his temperature readings. He has recorded an outside temperature of 17°F below zero when the temperature in the inner grow tunnel was 17°F above zero. The lettuce growing there was perfectly good and harvested for sale. He attributes the survival of the lettuce to some of the freeze protection mechanisms noted in the section on cold stress physiology and to the effects of super cooling.

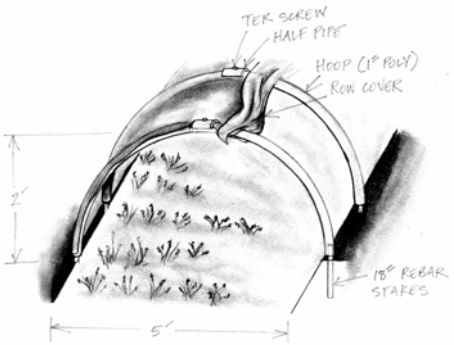
Supporting Interior Tunnels

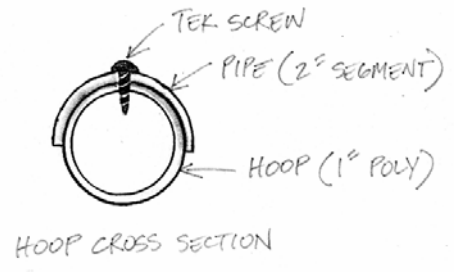
The Zemelskys and other farmers protect their winter crops by laying their “floating” row covers directly on newly seeded ground or over the top of growing crops without any supporting structure. But some growers have experienced a need to support their covers.

For low tunnels in the field, farmers often use hoops of 8 or 10 gauge galvanized steel wire to span their beds. Heavy gauge high tensile livestock wire can also be used. Usually the hoops are about 2' tall and are placed 4' apart. However, for winter production in high tunnels, several growers have noted that steel hoops are not appropriate because they are not tall enough to prevent the cover from touching the crop canopy. Generally plant tissue that comes in direct contact with frozen row cover will become marred and may eventually die.

Steve Moore makes hoops with 8 foot lengths of used polypropylene water pipe (3/4" to 1-1/4" diameter). The pipe ends of the 8' lengths are placed over 18-inch pins pushed three-fourths of the way into the ground on the edges of beds. Row covers may be suspended over these hoops just as would be done in the field.

Attaching the row cover to the bows facilitates ventilation and access to beds for harvest and other horticultural tasks. For each bow, cut a 2" piece of water pipe in half lengthwise. Using either a tek screw or drywall screw, fasten one of these small segments of pipe onto the top of each bow, sandwiching the polyethylene film between. *(See diagrams below.)* To open these mini tunnels, the cover is flung over one side. On a sunny day, the southern exposure is readily ventilated.





HOOP CROSS SECTION

Steve closes off the ends of his mini-tunnels with half circles of twinwall polycarbonate or waste polyethylene film. The tunnels themselves are covered with used greenhouse plastic cut to size. Each tunnel spans a single 5' bed, and is about 3' tall.

His tunnels within a high tunnel stay 15 to 20°F warmer than minimum outside temperatures in winter. In sunny weather, he finds it essential to roll or pull up the plastic to reduce unwanted heat within the low tunnels.

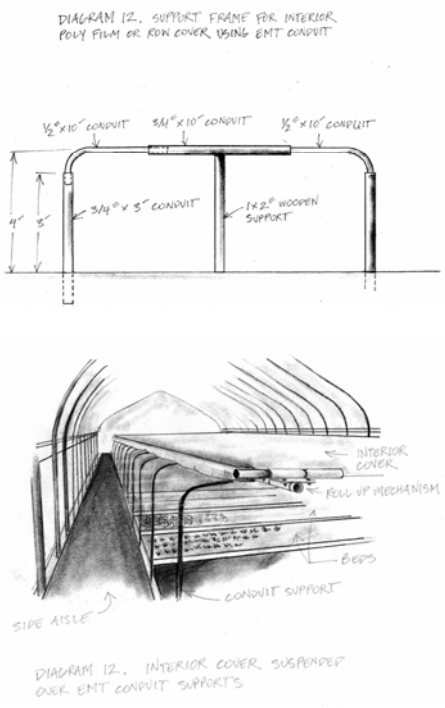
The plastic is also pushed out of the way for weeding, watering, and harvesting.

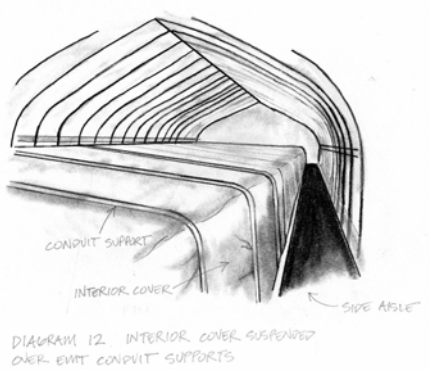
Some of his 30' wide high tunnels are laid out with a center aisle flanked on either side by beds running laterally across the tunnel *(see "Interior Tunnel Layout" on page 57).* Using this configuration, Steve is able to cover half of the cropping area (one side of the entire tunnel) with a single large sheet of row cover.

To suspend the row cover above the crops, Steve uses a long, rail-like hoop. He finds the larger, wider tunnel within the tunnel to be more effective in retaining heat than the smaller, single 5' bed inner tunnels. He has even created a roll-up mechanism for convenient venting and re-covering.

His framework for suspending the floating row cover is made of 1/2" or 3/4" thinwall electrical conduit. These metal pipes are spaced 4' on center to line up with the high tunnel bows. Steve bends one end of this metal pipe to a 90 degree angle to support the framework at a height of 30". He supports the middle of the 14' laterals with a piece of PVC pipe and uses a 2" x 4" to attach each metal conduit to a bow. Row cover can be laid loosely over this framework and scrunched up against the sidewall to open up the growing beds. Alternatively, Steve uses a swedged pipe—the kind used for roll-up sides—spanning the length of the high tunnel, to make a roll-up for the row cover. This roll-up is outfitted with a hand crank.

John Biernbaum created a row cover suspension frame almost 4' high for taller crops in his latest teaching and demonstration high tunnel at Michigan State University. *(See Diagram 12.)* The tunnel itself is 30' wide with 25' long lateral beds. Aisles on both sides in the colder and wetter edges conserve the center area for growing. The design uses a horizontal member for every bow and bed, both of which are 4' on center.





For horizontals, two 10' pieces of 1/2" conduit, each with a 90 degree bend on one end, cover 18' of the 25' bed length. A piece of 3/4" conduit in the center spans the remaining 7'. The ends of the 1/2" conduit fit inside of the 3/4" conduit. The 5' vertical support pieces (one at each end of horizontals) are made of 10' long 3/4" conduit cut in half. They are driven about 20" into the ground. The bend of the horizontal conduit raises the height a bit more.

Freeze Damage in Plants

There are three stages of freezing. As it gets colder, first the water in the soil freezes. Next, the water between a plant's cells freezes. Finally, water inside a plant's cells freezes, usually killing the plant.

Freezing of Water in the Soil
Water freezes at 0°C (32°F), yet, in the soil, dissolved solids lower the freezing point of water. When soil water freezes, it actually leaves particles and solutes behind.

In the process of freezing, water expands. While this can cause physical damage to the plant root, at times root cells are able to withstand pressures of up to 1000 atmospheres. This ability to withstand pressure varies seasonally and has been shown to increase with cold hardening. Freeze hardening is not completely understood. It is believed that the seasonal storage of sugars, sugar alcohols, and proteins within the cell aids in lowering its freezing point.

In addition to increased pressure, the frozen ground also prevents plants from taking up water. If they cannot replenish the water they lose through transpiration and other processes, they will die of desiccation (drying out). Winter wind can rob water from plant tissues, exacerbating the requirement for water. Both high tunnels and greenhouses are very effective in protecting against this type of desiccation.

Freezing of Inter-Cellular Water
When water changes phase (i.e., from liquid to solid), it releases significant amounts of energy. Freezing water literally releases heat!

In addition, in freezing temperatures, plants actually expel water from their cells into intercellular spaces. This increases the solutes within the cell, lowering the freezing point of cellular water and protecting the cells. This protective action can keep a plant from structural damage, even if it looks wilted or appears to be frozen.

Freezing of Intra-Cellular Water
Under most circumstances, when the temperature gets cold enough to freeze the water inside a plant's cells, the plant dies. It is ice crystal formation that kills the plant and not freezing per se. Rapid freezing of cells can occur without ice formation. Supercooling can also alter the freezing point, but this is a poorly understood process.

In Walking to Spring, their book about high tunnels on their farm about 100 miles southeast of Louisville, Kentucky, Paul and Alison Wiediger recommend keeping high tunnel plants on the dry side in the cooler months. "We don't let them wilt, but we don't keep them really turgid either…Dry conditions allow plants to accumulate more sugars in their cells, and acclimatize the cells to the cold."

"We can go in the cold frame on a sub-freezing morning (say below 20°F) and all the plants look dead—lying on the ground, you know the frozen look! But by 10 AM or so, especially if the sun is out, they are all upright and beautiful again. It breaks your heart the first time you see it, but it invokes wonder two or three hours later."

"Last year we had the soil at a good moisture level in mid-November and we didn't need to water until February…When we need to water [in the winter], we watch the weather forecast for a window of several days and nights above freezing. We water on the first day of that window, so that by the time the freezing temperature returns, the plants have adjusted to the extra water."

Soil and Crop Management

Soil Management

Most high tunnel growers produce their crops in the soil on which the tunnel rests; therefore, the quality of the soil under your tunnel will be critical to your success. Given that you will spend a good deal of money to construct a premium growing structure, it makes sense to complete the job by making certain the soil environment is also a superior one.

A coarsely textured, well-drained soil is best for high tunnel production. Clays, because they drain and warm relatively slowly and have a tendency to accumulate salts, are the least desirable soils for high tunnels. *(See "Salinization" on page 56.)* However, growers have been able to make do with a wide variety of soils, amending and improving them over time.

The structure of the soil in the relatively small space under a tunnel can be dramatically altered. The addition of substantial amounts of compost or leaf litter will increase the organic matter in the soil, thereby increasing the soil's capacity to provide oxygen, water, and nutrients to the crop.

To lighten heavy clay soils, organic matter can be added in a variety of forms, besides finished compost. For example, aged wood shaving with leaves or a small amount of manure or another organic nitrogen source can improve the structure of a heavy soil. Avoid fresh wood shavings as they will tie up soil nitrogen. John Biernbaum improves the soils in his high tunnels with significant amounts of animal bedding from weekend livestock shows on campus. This bedding has a low concentration of manure.

Monitoring Soil Health

A good monitoring program evaluates the physical and biological composition of your soil as well as its chemical makeup.

Several important indicators of soil physical health are easy to monitor. To determine if your soil is compacted, for instance, you can use a penetrometer, a tool that measures resistance to penetration. Although these devices are expensive, they can sometimes be borrowed from your local Extension office. You may make an effective penetrometer at home by putting a simple handle on a straight piece of rebar. The tip should be sharpened to a dull point. You should be able to push it at least 12 inches down into the soil before encountering resistance.

You can also check plant rooting depth. If you observe plant roots to be growing horizontally at a shallow depth, then the soil is probably too compacted for good root penetration or water drainage, and should be loosened by some form of tillage. When preparing the soil for planting or when removing crop debris, take the time to determine if earthworms are present and at what level.

Traditional chemical analyses are as important in tunnels as they are in the field. Nutrient and organic matter levels, soil pH, and electrical conductivity (salts) should all be measured periodically.

Adding Nutrients

High tunnel production is intensive, with faster growth than typically found in field production. In some cases, three or even many more successions of crops are grown in a tunnel during a single year. (Greens growers can produce as many as eight crops per year in the Northeast.) Because of this intensity, high tunnel soils benefit from relatively high applications of compost, fertilizer and other soil amendments. Similarly, large applications of organic matter are also beneficial.

Farmers approach nutrient management in high tunnels in a variety of ways, many of which are similar to their field practices. One notable absence from high tunnels is the practice of cover cropping, even on farms that employ cover crops in their fields. Farmers have offered several reasons for the lack of interest in cover cropping in high tunnels: first, there is no risk of erosion inside a tunnel; second, space is at a premium; and third, windows of time for cover cropping are minimal, particularly for farmers who use their tunnels year-round. Some cover crops could potentially serve as over-wintering habitat for pest species.

Many farmers rely heavily on compost as the foundation of their fertility programs. A balanced compost added to a good soil can provide the range of nutrients required for crop development, and some farmers depend upon it exclusively for fertility. Too much of a good thing can create its own problems, however. Using too much compost is not only expensive; it can also lead to the build-up of salts and outbreaks of root-feeding arthropods such as tiny symphylans.

Several farmers reported adding large amounts of compost to a new high tunnel, and then adding modest levels thereafter. For a new tunnel at Slack Hollow Farm, compost was added at the rate of 10 tons per acre. The Blomgrens also load up at the onset. Then, before each new crop, they spread just five gallons of compost per 40 square foot bed—a layer of less

than an eighth of an inch. They add this compost to enhance microbial activity, nutrient availability, and soil water-holding capacity. These quantities improve the soil's structure, but don't affect soil texture. Compost must be free of viable weed seed.

Composted manures typically have an excess of phosphorus in relation to nitrogen. If compost is applied at a rate designed to meet crop nitrogen needs, phosphorus will be oversupplied. Farmers who have recognized this problem are reducing their compost applications and applying alternative sources of nitrogen. When determining fertilizer rates, they are sure to credit the compost for the nutrients it has supplied.

When soils are cool in the spring, microorganisms are not converting nitrogen to an available form fast enough to sustain good plant growth. This is the time to consider adding a soluble nitrogen source, such as Chilean nitrate (guano).

Just as periodic soil testing is advisable, it is also wise to have compost tested for nutrient availability, pH, and the presence of substances like salts or toxics that could be detrimental to crops. (A persistent herbicide called chlorpyralid has contaminated composts containing lawn clippings and other materials.) Farmers can request test results from commercial composters or submit compost samples to laboratory services like Dairy One.

Some farmers manage soil fertility more strictly by the numbers and with less bulky materials. Fertigation, with soluble fertilizers injected into a drip irrigation system, is the basic program employed by many farmers who operate in controlled or managed environments, such as high tunnels and greenhouses. Growers, like Keith Cramer at Cramer's Posie Patch in Pennsylvania, incorporate a chemical fertilizer into the soil prior to bed preparation. Steve Groff, also in Lancaster County, Pennsylvania, also uses his drip irrigation system to supply his high tunnel tomato crop's nutrient needs.

Like fertigation, foliar feeding makes soluble nutrients immediately available. Two farmers in this project foliar feed Epsom salts, kelp, and fish products respectively. This practice can be used with a variety of micronutrients as well.

Day Length Affects Flowering

If you extend the season at either end to achieve earlier or later harvest dates, some cut flowers will not perform as anticipated. Plant physiologist Chris Wien, a Cornell professor, realized that day length was the culprit when his several of season extension trials failed.

He attempted to get sunflowers to bloom in the spring rather than summer and he started *Rudbeckia hirta* (Black-eyed Susan) late to get fall flowers. To prevent mishaps, he suggests experimenting on a small scale before you decide to grow a flower cultivar off-season. He found that seed catalogs are not always correct on this point.

(See "Daylength affects rudbeckias, sunflowers," June 2006 Growing for Market.)

Nitrate Uptake in Low Light Greens

It has been well documented that the ingestion of excessive nitrates from our diet and water can be detrimental to human health, especially in the very young. The European Union has set limits for nitrate levels in greens. The United States has not yet taken action. Farmers should be aware of this food safety issue and act accordingly in order to produce healthy food.

Greens grown in low light (off-season, winter production) have greater potential to accumulate unhealthy nitrate levels. Plants can take up nitrates in excess of their needs. There are a number of management strategies that can moderate nitrate uptake and improve its assimilation, giving the end result of healthy greens with low levels of nitrates.

The range of suggested practices includes:

- Harvest greens later in the day.
- Do not sell older, more mature leaves.
- Supply adequate soil moisture.
- Maintain soil pH on the high side of the normal range.
- Provide balanced soil fertility.
- Grow in warmer temperatures.
- Select cultivars that better assimilate nitrates (when this characteristic is known).
- Use legume-based compost as a source of nitrogen.

Salinization

Like irrigated lands in arid climates, high tunnels may be vulnerable to the accumulation of salts. If allowed to build up, salts may cause damage to crops. If soils within the high tunnel are well-drained, irrigation water may leach some of the salts through the soil profile, as occurs with adequate, regular precipitation outside. However, if the soil is poorly drained, accumulated salts will actually be brought up to the surface when soil moisture evaporates.

The application of synthetic fertilizers, animal manures, or manure-based compost (all with significant salts) can result in the build up of salts over time in high tunnel soil. Sodium chloride—table salt—is not the only problematic salt in soil. At excess levels, other salts also cause drought-like stress, interfere with seed germination, and inhibit plant growth. Plants with higher drought tolerance typically handle increased soil salt concentrations better than more drought susceptible plants. Nutrient uptake and other metabolic processes can also be disturbed by soil salinity.

In addition to directly affecting the plants, elevated salinity levels have been anecdotally associated with damaging outbreaks of symphylans, tiny arthropod pests (also known as garden centipedes) that feed on plant rootlets and root hairs. “The effects of high soil salts aren’t pretty on plants or income,” says Steve Moore, speaking from personal experience.

Salt stress can mimic the symptoms of drought stress, nutrient deficiency, and root rots caused by soil-borne pathogens. Thus, it makes sense to pursue a proper diagnosis of the problem. One way to test for salinity is with an electrical conductivity (EC) meter (available for under $100). *(See “Ben Meadows” and “Pike Agri-Lab” on page xx.)* Electrical conductivity is a measure of the ability of a solution to transmit an electrical current. The higher the salt level, the greater the current. EC readings are usually given in deciSiemens per meter (dS/m). In general, readings over 1 dS/m may indicate problems for some fruits and vegetables. When comparing your EC values to those that are published, be sure you are using equivalent sampling procedures. Otherwise, you will not be comparing “apples to apples.”

Salinity Tolerance of Common Vegetables Grown in Utah

Crop	Threshold value	10% yield loss	25% yield loss	50% yield loss
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
Asparagus	5.0	8.0	11.0	13.0
Beans	1.0	1.5	2.3	3.6
Beets	5.3	8.0	10.0	12.0
Broccoli	2.7	3.5	5.5	8.2
Cabbage	1.8	2.8	4.4	7.0
Cantaloupe	2.2	3.6	5.7	9.1
Carrot	1.0	1.7	2.8	4.6
Cauliflower	2.7	3.5	4.7	5.9
Celery	1.8	3.5	5.8	10.1
Corn, Sweet	1.7	2.5	4.0	6.0
Cucumber	2.5	3.3	4.4	6.3
Lettuce	1.3	2.1	3.2	5.2
Onion	1.2	1.8	2.8	4.3
Peas	0.9	2.0	3.7	6.5
Pepper, Bell	1.3	2.2	3.3	5.1
Potato	1.7	2.5	3.8	5.9
Radish	1.2	2.0	3.0	8.0
Spinach	3.7	5.5	7.0	8.0
Squash/pumpkins	3.9	4.9	5.9	7.9
Sweet Potato	1.5	2.4	3.8	6.0
Tomato	2.5	3.5	5.0	7.6
Turnips	0.9	1.9	3.1	4.9
Watermelon	2.0	2.5	3.5	4.5

(Continued on next page.)

"Salinization" continued from page 56.

EC is the electric conductivity of the extract using a water saturated paste solution. Note the reduction of yield as a function of increased salts. *From Utah State University Extension, http://extension.usu.edu/files/agpubs/salini.htm.*

The following strategies can help reduce soil salinity in high tunnels:

- Provide adequate soil drainage through natural means (locating tunnels on well-drained soils) or improve soil drainage through artificial means (drainage tiles or pipes).
- Allow the soil to dry and then scrape off a top layer of soil and salts. Add more soil as needed.
- Flush out the salts periodically. This can be done either by removing the cover or by flooding the high tunnel during the off-season. This second approach requires a great deal of irrigation water, however. When changing the poly film every four years, consider leaving the tunnel uncovered and exposed to natural precipitation for a period of time.
- Reduce the amount of salt-forming fertilizers and use vegetable-based compost containing legumes.

In caterpillar and multi-bay tunnels such as Haygroves, which are uncovered during the off-season, salt build-up is eliminated because precipitation flushes away the excess.

Adapted in part from "Salt Tolerance of Plants", Alberta Government Agriculture, Food, and Rural Development, www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex3303.

Interior Tunnel Layout

The growing space in a high tunnel is often broken up into beds. Some farmers create raised beds slightly or substantially higher than the surrounding pathways by adding compost and/or soil. Beds can be made manually with hand tools, or mechanically with equipment such as a roto-tillers or bed shapers. A good tunnel layout optimizes crop production and accessibility. Farmers strive to maximize the growing area since space is costly and limited, while allowing ready access to all portions of the tunnel.

Longitudinal Beds

Setting up the rows or beds along the long axis of the tunnel is the most typical high tunnel layout, and is especially suited to growing tomatoes or other trellised or staked single row crops *(see Diagram 13).* Tomatoes benefit from goods air circulation, which longitudinal rows can provide via large gable end vents and doors.

A long row configuration has other advantages. It makes it easier to utilize inner row covers on a bed-by-bed basis. Fewer connections are needed for T tape. Long rows facilitate the use of tractor-driven equipment. They can also make for a simpler system, especially if only one or very few different crops are grown in the tunnel. Long rows also allow the easier use of overhead grow troughs.

Plants grown along the perimeter of a tunnel may exhibit an "edge effect," with poorer growth common closest to the side walls because temperatures are lower there. Wider high tunnels have less of this chillier growing space relative to their overall area than narrower high tunnels, and this should be considered when determining high tunnel size. Some farmers reserve this space for especially hardy crops. For example, the Zemelskys grow hardy pea tendrils around tunnel perimeters in winter.

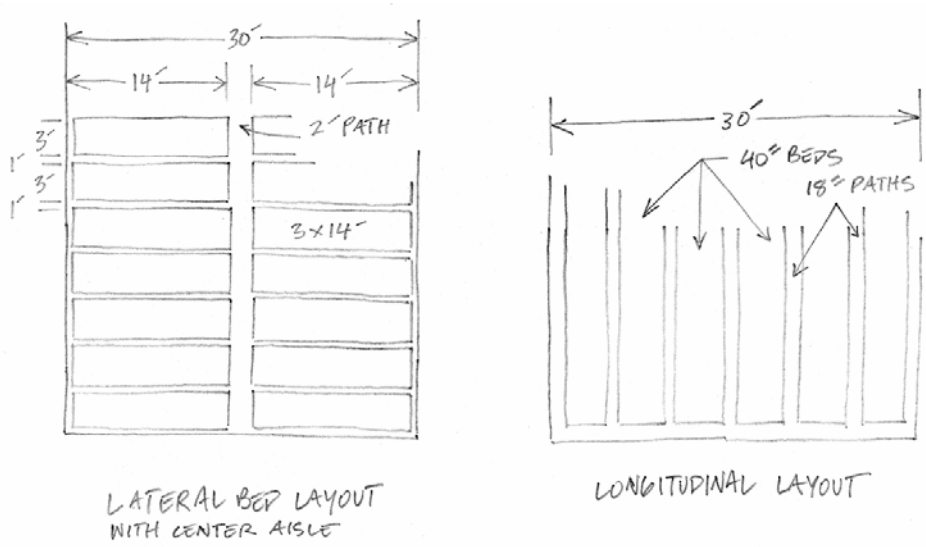


DIAGRAM 13. BED LAYOUTS

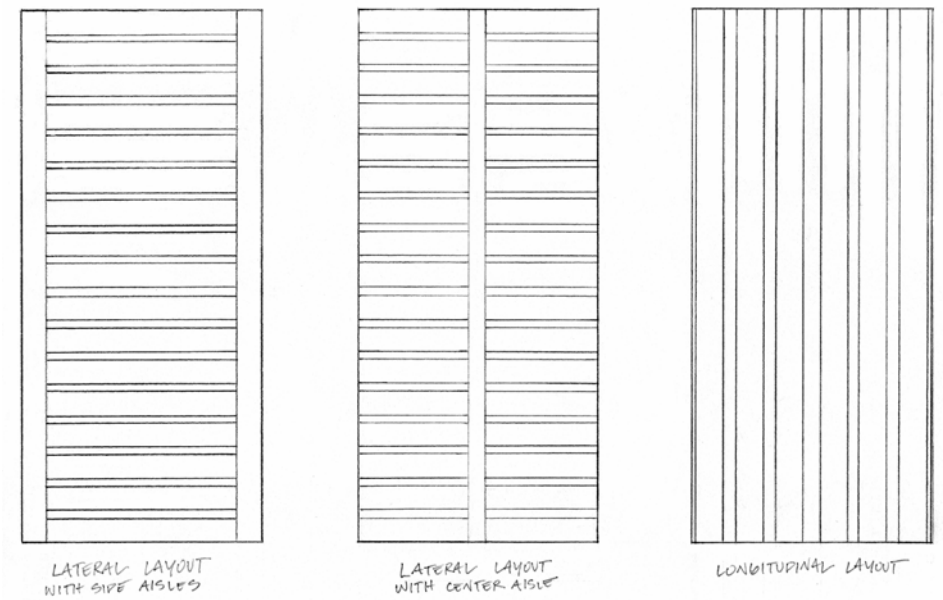
Lateral Beds

Orienting beds laterally across the width of a high tunnel is another solution to the twin challenges of access and crop optimization *(see diagram below).* This layout utilizes a center aisle, with beds running perpendicular to the aisle. Even in a 30' wide tunnel, a worker never has more than 14' to go from the aisle to the far end of a bed. For harvesting as well as for transplanting, this kind of accessibility means a lot. Using this configuration, the farmer can afford to make the single, center aisle generously wide without worrying about squandering prime growing space. In fact, this layout provides slightly more growing space than one divided into longitudinal beds.

The central aisle makes it easier to move materials in and product out. Worker movement is also more efficient. Flats for transplanting and harvest lugs can be put in the lateral pathways so that workers don't have to walk over them when coming and going. A monorail or overhead tram can even be installed to mechanically move materials down the center. The central aisle layout simplifies the use of hoses. A drawback for those using drip irrigation is that many more drip starts are required because there are so many more short beds. A 30' x 144' high tunnel with a center aisle and beds spaced 4 feet apart has as many as 70 individual beds.

For tunnels with an East-West orientation (which is best for winter growing), configuring lateral North-South beds will result in less shading of crops. When using interior covers, the lateral bed layout enables the farmer to cover the entire tunnel with just two pieces of row cover, one to the right of the central aisle, and one to the left. Steve Moore has designed a simple rail system that supports the row cover over each half of the tunnel's beds, making covering and uncovering a relatively quick process *(see page 52 for the "tunnel within a tunnel" discussion).* This approach saves labor and retains heat better.

Lateral beds can also be laid out across the entire structure, with aisles situated along the long sides of the tunnel. This layout makes sense under cold growing conditions, as the edges offer the least protected microclimate, but has a drawback in that it situates aisles where there is the least amount of headroom in a high tunnel. Slack Hollow Farm is currently using a variation on this layout.



Crop Establishment

Seedbed Preparation

High tunnel growers use both flat and raised beds, and some use both in different situations. Raised beds are especially beneficial to spring crops because they improve soil aeration and facilitate water drainage, resulting in warmer soils, increased microbial activity and nutrient availability, and enhanced root development.

There are many ways to prepare the seedbed within a high tunnel. The spectrum of possibilities ranges from hand tools to small-scale, tractor-powered field equipment. Self-propelled roto-tillers are an intermediate option between tractors and hand tools. As long as a tractor can be found that fits inside the structure, equipment such as chisel plows, spaders, tillers, bed shapers, and mulch layers can be used in high tunnels. Equipment manufacturers have begun to make specialized tunnel-scale equipment. Ample ventilation will make the use of diesel and gasoline engines in high tunnels a safer and more tolerable task.

Winter growing pioneer Eliot Coleman has devised a market garden production system relying solely on hand tools, some of which he designed. After adding soil amendments, he loosens the soil with a broad fork (a 24" wide fork that harnesses body weight rather than muscle power to loosen soil without inverting it). Next, the beds are leveled, and debris, roots and rocks are removed using an extra-wide bed preparation rake. Short tubular fingers (which can be purchased with the rake) can be placed over selected rake tines to individually mark rows or a grid pattern for seeding or transplanting. *(See "Johnny's Selected Seeds" on page 69.)*

Seeding and transplanting

Because of the tight spacing in a high tunnel, seeding and transplanting is usually done manually. Northern producers use transplants for long-lived, warm weather vegetables and for most cut flower species (other than those grown from vegetative structures like bulbs or corms). In contrast, direct seeding is the popular method for starting short season, more closely spaced crops like salad greens and spinach.

There are a variety of push seeders on the market costing between $100 and $500 and up. Earthway Company manufactures one of the least expensive one-row seeders on the market. Several of these light-weight plastic seeders can be attached in a gang and pushed by hand. The more durable old Planet Junior seeders are still available from used equipment dealers *(see "Tools" on page 70)* and on eBay. In addition, Planet Junior production has resumed. Johnny's sells a European push seeder modeled after the Planet Junior (though welded rather than cast) for half the price of the new $500-plus version. One-, four-, and six-row pin-point seeders are another mainstay of tunnel growers. Designed for seeding salad crops in close-row spacing, they create uniform plantings that do not need to be thinned.

Crops that are transplanted in the field are also usually transplanted in the high tunnel, including tomatoes, peppers, eggplants, cucumbers, summer squashes, melons, basil, and other herbs. Early season transplants are usually started in a heated greenhouse (or in compost-heated hot beds within the high tunnels), and transplanted into the unheated high tunnel when the climate becomes conducive to their growth.

Most cut flowers are also transplanted. For some slow-growing or hard-to-germinate species, purchasing plugs from a nursery can save on labor and fuel costs. However, plugs bring the risk of thrips and other pest outbreaks that can cause difficulties in the entire house or, worse, the multiple houses into which the starts from the greenhouse are transplanted.

Direct seeding is not the only way to start salad and braising mix crops like Asian greens, lettuces, chards, bok choys, and other relatively quick-growing greens. For greens following tomatoes, Ted Blomgren finds that transplanting allows him to keep the tomatoes in the ground three weeks longer. Then, within days of removing a tomato planting in the fall, the newly transplanted winter crops are well-established for his winter CSA.

Additional tomato yields, in his view, more than offset the cost of soil mix and labor for tending flats of seedlings in the greenhouse. This approach also reduces the risk of germination failure and gives him the plant stands for which he is looking.

For these mid-fall plantings, Ted sows up to five seeds per cell in 98-cell trays. This seeding yields clumps of plants that are set six inches apart within and between rows in 3' wide high tunnel beds. Arugula, kales, Asian brassica greens, chard, and Red Salad Bowl (his favorite lettuce cultivar for winter growing) are among the crops he grows this way.

As a rule, the way to boost the economic return from the high tunnel investment is to keep its growing space well utilized. Intercropping and succession cropping are strategies for making optimal use of space. Interplanting scallions or fast-growing greens with slow-growing tomatoes, for example, are ways to boost economic returns from a high tunnel.

Watering

Careful attention should be paid to irrigation in high tunnels. The plant canopy in a high tunnel is usually greater than it is in the field, and water needs are correspondingly greater. During the spring and summer, when high tunnel crops are growing especially fast, their demand for water is quite high. It is not uncommon for high tunnel tomato and cucumber growers to irrigate every day during the height of summer. Water needs shrink as the days become shorter and colder. By winter, very little irrigation is required. Over the course of the year, and depending upon the growth stage of a crop, growers will adjust the amount of water provided.

Drip irrigation is a common method for providing water to plants in high tunnels. High tunnel systems are identical to those used in the field. Drip tape delivers water without wetting foliage. Preventing prolonged leaf wetness, which contributes to crop disease, is especially important in warm season crops. Drip systems are often automated with a timer to ensure regular watering. Using multiple drip lines on a bed will also provide for the water needs of multiple rows of crops. Drawbacks to drip irrigation include the cost and amount of plastic involved and the fact that drip tape interferes with crop cultivation.

Direct seeded plantings, especially the greens and root crops that are closely spaced, may be less suited to drip irrigation. For these applications, overhead sprinklers have a place in high tunnels. To break the disease cycle, watering should be done in the morning to allow plants to dry before evening.

An irrigation system can be devised that uses either drip tape or overhead sprinklers, depending on the crop rotation in the high tunnel. Low pressure, small volume micro sprinklers are available that can run off the same main trunk as drip tape, making the conversion of an irrigation system simple. New irrigation technology and products are becoming available all the time.

Pest Management

Weed Management

No farmer wants to spend precious time combating weeds. Besides competing with crop plants for light, nutrients and water, weeds may serve as reservoirs for plant pathogens and arthropod pests such as thrips, aphids and spider mites. These pests may also find crop plants attractive. They often act as plant disease vectors, too. Weeds can also turn harvesting and processing of certain crops like salad greens into an aggravating task. For these reasons, and because weeds that produce seeds will cause trouble later, allowing weeds to grow is not a good idea.

Weed problems are compounded by the enhanced microclimate of a high tunnel. Its longer season and more moderate cold season conditions provide a perfect habitat for many weeds. For instance, chickweed, a winter annual that flourishes under the mild winter conditions present inside a greenhouse, can cause serious difficulties for winter salad greens growers.

Whether inside a high tunnel or in the field, reducing the weed seedbank in the soil is a key principle in weed management. Unless preventative measures are taken, high levels of weed seeds are likely to translate into high weed pressure. The good news is that within the finite boundaries of a high tunnel, farmers have found it possible with vigilance and timeliness to regain the upper hand on weeds, even after they have raged out of control.

High tunnel growers use hand hoes, stale seedbed techniques, and plastic and organic mulches to manage their weeds. Hand hoes are particularly well suited to the intimate environment of a high tunnel. If used when weeds are very small, hand hoes provide fast and effective weed control. Often, a single well-timed hoeing will produce a weed-free salad or cut flower crop. If given a weed-free start and good growing conditions, these fast-growing crops should out-compete weeds. Hand hoes are available in several configurations (e.g., oscillating stirrup hoes, push-pull hoes and collinear hoes), and in sizes ranging from 3" to 12" wide. *(See "Tools" section on page 70.)*

Stale Seed Bedding

Stale seed bedding is a versatile approach that allows the grower to nip weed pressure in the bud. The idea is to encourage weed seeds to germinate and then to kill the emerging weed seedlings before they can take hold. This process is repeated up to several times in rapid succession typically before the crop itself is planted.

As a new grower, David Zemelsky at Star Light Gardens in Connecticut experienced an incremental build up of the weed seedbank in his high tunnel beds. Weediness ultimately impacted yields in his greens. As a result of his struggle with weeds, he has become a believer in the value of stale seed bedding.

As an example, consider stale seed bedding for a winter crop of baby brassica greens following tomatoes. First rip out the tomato vines, add soil amendments, and renovate the bed. To avoid bringing up new weed seeds, do not invert the soil! Instead, loosen the bed with a broad fork as one of several ways to achieve this end. After the bed is readied for planting, firm it and, if necessary, irrigate to encourage weed seeds to sprout. When the new weed seedlings are still in the white thread stage, use a propane flamer or very shallow tillage with a stirrup hoe to destroy them. Take care not to bring up more weed seeds from lower in the soil profile when tilling.

Carrying out stale seed bedding requires a several week break in the cropping cycle. Because high tunnels are an expensive horticultural environment compared to open fields, it is worth making this sacrifice to optimize growing conditions before weed pressure gets out of hand. The farmer must be an effective manager to take advantage of the narrow window available in the crop sequence for stale seed bedding.

Another weed problem that growers may face is the encroachment of perimeter vegetation, including quack grass, into a tunnel. If regular mowing is not sufficient, try landscape fabric as a weed barrier. It should be well secured on bare ground along the outside perimeter of the tunnel. Mow right up to it. A foot wide barrier of landscape fabric on a tunnel's inner perimeter is also an option.

Mulching

Mulching with organic materials such as rye or oat straw is an option for weed prevention in crop beds for tomatoes and the like, especially if additional soil warming is not essential. Straw retains soil moisture and eventually breaks down into soil organic matter, with no disposal needed.

However, straw left in place indefinitely can attract mice and other unwanted rodents. Organic mulches can exacerbate slug infestations. Straw mulch may also interfere with the functioning of precision seeders. Andy Jones of Intervale Community Farm experienced this problem when he direct seeded greens after a straw-

mulched tomato crop. He warns, "Even a fine toothed landscape rake leaves behind enough bits to give the planter (and me) conniptions."

Straw has another role between beds. Ted and Jan Blomgren at Windflower Farm use straw to prevent weeds between beds, whether they are mulched with plastic or left bare.

For long-lived crops such as tomatoes, peppers, melons, and cucumbers, many farmers opt for synthetic mulches to stymie weeds and heat the soil. Their use in tunnels is no different from field situations. Black (or other colored) plastic can be applied with a mulch layer or laid down by hand. U-shaped ground staples—6" galvanized steel or plastic staples—are one way to pin down this plastic film.

After amending the soil in preparation for planting, Tim and Janet Taylor, at Crossroads Farm in Vermont, cover the ground in their high tunnels from wall to wall with a solid sheet of heavy black plastic mulch. Steve Groff, at Cedar Grove Farm in Pennsylvania, plants tomatoes into heavy-duty landscape fabric. At Cramer's Posie Patch, white plastic mulch does double duty—it suppresses weeds and cools the soil for cool season cut flowers.

One way to make planting holes in landscape fabric is to use a propane torch. Minor (or major) mishaps can occur, as the material is flammable, and care should be used. Cutting an "X" in the fabric is another method. Both approaches have their proponents and detractors.

Plastic mulch can harbor plant pathogens, some of which may overwinter in folds of the material so its reuse can be risky. The bacterium that causes Bacterial Canker in tomatoes, for example, is thought to overwinter on tomato stakes and mulches. Where possible, rotate landscape fabric for use with other crops that do not host the same diseases.

Chris Lincoln at New Minglewood Farm used 6' wide pieces of landscape fabric to cover the ground in and between four 10' x 100' walk-in tomato tunnels. With 2' between each tunnel and two rows within each tunnel spaced 6' apart, he was able to plant the tomato transplants at the intersection where one piece of fabric ended and the next started.

Managing Diseases in High Tunnels

Many growers have chosen high tunnels, in part, because they offer protection against the diseases their field crops encounter. Septoria leaf blight, (one of the most troublesome diseases of tomatoes in New York State), for example, is virtually unheard of in high tunnels. Crops inside high tunnels usually experience much shorter periods of leaf wetness than crops in the field. Diseases will not occur in the absence of the environmental conditions necessary for the existence of the pathogen that causes them.

Nevertheless, disease is not eliminated in high tunnels. Leaf mold (*Fulvia fulva*) on tomatoes, for example, has become increasingly commonplace. The danger of an infestation is highest when airflow inside the tunnel is low and relative humidity is high. Selecting resistant varieties, reducing plant populations, increasing tunnel ventilation (by adding gable-end vents, etc.) and promoting improved air circulation inside the tunnel (e.g., adding fans) are each parts of a potential solution to the problem.

Growers have reported other disease problems as well. These include bacterial canker and Verticillium wilt in tomatoes; powdery mildew in tomatoes, cucumbers, squashes, late season lettuces, and flowers; Alternaria leaf spot in brassicas; Fusarium root rot in lisianthus; and leaf spot in Bells of Ireland, among others.

Tomato growers should pay careful attention to variety selection. Disease-resistant varieties with good yields and eating qualities are increasingly available. Where the incidence of soil-borne diseases has been high, some growers have turned to grafting. Mike Collins, who grows greenhouse tomatoes in southern Vermont, grafts 'Buffalo' scions onto a vigorous and disease-resistant rootstock. The practice increases his cost of production but it also provides him with superior yields of excellent tasting fruit.

A preventative approach to disease management is the best strategy. In general, it is best to take steps to enhance air movement and reduce relative humidity. The following tactics are also recommended:

- Provide adequate plant-to-plant spacing to avoid excessive shading and enhance air circulation.
- Select disease-resistant varieties.
- Maintain a pest-free environment. Keep high tunnels free of the weeds that harbor diseases and the insects that transmit them.
- Practice good sanitation. Remove diseased crop residues, and sanitize mulches and trellises.
- Provide the nutrients and water necessary for optimal crop growth.
- Utilize a good crop rotation.
- In the absence of a winter crop, open the tunnel so that disease spores can be killed by winter temperatures.

Ecological Insect Management in High Tunnels

By Steve Moore

Insect pests generally cause less damage in high tunnels than they do in the field, in part, because the crops inside are growing at a time when pests are less active. The tunnel itself functions as a barrier to insect pests, at least until temperatures warm to the point that the tunnel sides are open much of the time. Nevertheless, insects in high tunnels can cause economic losses. Aphids and thrips, both of which have fairly broad host ranges, can be particularly troublesome in high tunnels. And high tunnels can also harbor pests and allow them to hatch earlier than outside.

Years of experience have proven the effectiveness and shortcomings of a biologically-based high tunnel pest control program. Here are some important considerations to achieve good control of potential "pests."

Develop Healthy Soil

Healthy, balanced soil is the single most important factor in attaining healthy plants. Our most important amendment is well-made biologically active compost. We also use this medium for our flats and transplants. We avoid excess nitrogen as it compounds pest and disease problems and it makes the food less nutritious.

A research project reinforced my intuition that healthy soil leads to healthy plants. As part of a three-year beneficial insect project, we reared beneficials in our own greenhouse. We acquired aphid-infested tomato plants, re-potted several of them, and placed them in insect cages. A colleague who was counting the insects remarked that only certain plants had any aphid egg deposition. After a few weeks, we took a minute together to look at the plants. We found that only the plants in prepared, sterilized media were hosting the aphids while those in our compost were free of aphids.

Encourage Beneficial Insects and Other Arthropods

According to the old adage, "diversity leads to stability," we are aiming for a balance between the "good" and "bad" organisms. Eliminating all of the bad (pest) organisms invites trouble, and in the absence of beneficial insects, pests can quickly become a problem.

Avoid synthetic pesticides and use natural and botanical pesticides sparingly. As a general rule, beneficial insects are more sensitive to pesticides than pests. Synthetic chemicals often have long residual effects. You will be amazed at the number of beneficial insects indigenous to your greenhouse when you don't suppress them.

Don't bring in plants that may have pests or pesticide residues. We learned this the hard way by accidentally bringing in tomato plants sprayed with the insecticide, Lannate (active ingredient methomyl). The long-lasting residues of this insecticide are lethal to most beneficial insects for 8 to 12 weeks. Because the Lannate-treated tomatoes wiped out beneficial populations that came in contact with them, we were unable to introduce beneficial insects in a timely fashion. Although we applied other strategies, the aphids almost got ahead of us. *(See "Koppert Side Effect Database" on page 74.)*

Another high tunnel grower reports that pests come along with every shipment of plugs. For example, fungus gnats arrived with lisianthus plugs almost every time they order them.

Remove weak and injured plants. Just as wolves following deer herds will cull the weak and old, insect pests and plant disease organisms will hone-in on those plants that are best not left in the gene pool. As farmers, we select for traits such as yield, climatic adaptability, or taste. Yet we often ignore pest susceptibility traits by substituting chemical controls instead.

Know, Scout, and Monitor

Know your insect neighbors at all stages of their life cycles. If you have ever looked at the larval stage of a ladybug, you will agree that they look anything but helpful. Yet even in this stage, they are aggressive pest controllers. A good insect identification book *(see page 74)* that shows the various insect life stages and lists their primary food sources is indispensable.

Careful scouting will enable you to discover insects and diseases (and estimate their incidence) before it is too late to manage them. In scouting, typically 2% of the plants should be observed. Over time, you will become familiar with which insects like which plants and where to look for them. For example, whiteflies "like" the third set of leaves down on tomato plants.

Sticky cards are a well-accepted and inexpensive monitoring tool. Yellow cards attract most insect pests, including whiteflies and aphids, while blue cards attract thrips. Attach these cards to posts or strings with clothespins. Write the date on the card so it serves as a record of pest activity. Each card can be used for an entire month. For the first week, remove the protective paper from one half of one side of the card. The next week, place clear plastic wrap over the used section and remove the protective cover from another half of the card. The next week, continue on the back of the sticky card. At the end of the four-week period, the card provides a snapshot of weekly changes in the populations of certain pests.

In addition to scouting and sticky cards, there are other monitoring practices. Index plants attract specific pests. For example, to determine if thrips are present, use New Guinea Impatiens, a plant they favour. Plants like these can also function as a trap crop that will be destroyed in order to reduce the specific insects. Exercise caution when using this approach. Early in our greenhouse experience, we grew Impatiens transplants for sale in part of a tomato greenhouse. This was a big mistake, as we invited every thrips in the county to infest our tomatoes.

Pest Control Options

Sometimes an insect pest population exceeds the level at which beneficial insects can provide adequate or timely control. Faced with this situation, I might turn to a biorational insecticide, such as a fatty acid like Safer's Soap. A soap application can knock down localized outbreaks of certain pests (e.g., aphids and whitefly), allowing beneficial populations to gain an advantage.

A drawback of this strategy is the potential harm to beneficial insects populations, for even these soaps have a lethal effect on some beneficials. Restrict the use of botanical pesticides such as rotenone and pyrethrum. Though natural, these pesticides can devastate beneficial insects as well.

Beneficial insects can be purchased to help bring particular pests under control. It is absolutely critical to introduce beneficial insects before the pest population can no longer be controlled by beneficials. Therefore regular monitoring is an essential component of any biological control program.

In my climate and growing conditions, I have introduced parasitic wasps such as *Aphidius colemani* to control aphids and *Encarsia formosa* to control whitefly. Beneficial insect suppliers can help you determine what species of parasitoid or predator will be most appropriate and effective for your situation. These suppliers provide basic directions on how to use them and often will help with troubleshooting as it is in their interest for you to be successful with your beneficial introductions. *(See "Beneficial Insects" on page 69.)*

Provide Food and Habitat for Beneficials

Growing in the soil (as opposed to hydroponically) allows many beneficial insects to complete their life cycles and hence respond to pest pressures. For example, *Amblyseius cucumeris,* a predator mite that relishes thrips, needs the soil for part of its life cycle. Additionally, undisturbed soil will encourage ground and rove beetles, generalist insect predators.

Some beneficials cannot fly. These beneficials are easily stranded on a plant "island" after they have eaten all the pests within their reach. When the canopy of plants inside a high tunnel touches, it provides a concourse for wingless beneficials such as predatory mites and midge larvae. This allows them to walk between plants so they can access and attack their pest prey. If your plants don't touch, you need a different beneficial.

Feed beneficial insects. One study documented a 600% increase in beneficial insects where they were fed. One nectar substitute is 3 to 6 ounces of powdered sugar dissolved in a gallon of water. A pollen substitute is a half-pound nutritional yeast dissolved in water. Spray these solutions every week to 10 days when you see pests. When using these nectar and pollen substitutes, exercise caution about foliar diseases.

Insectary Crops

We establish insectary crops for food and habitat. These are plants that flower rapidly and are good nectar sources, providing high-energy food for beneficial insects. Excellent insectary plants include dill, cilantro, and others in the *Umbelliferae* family; yarrow; sea holly; and crimson clover. In a 30' x 96' hoop house, we often plant 10 to 12 square feet of permanent insectary plants throughout the high tunnel.

"Banker plants" are host plants grown to rear pest species that are not harmful to the cash crop. Banker plants can be grown in the high tunnel. The pseudo-pests raised on the banker plants attract and increase the population of beneficial insects that can control the "real" pests on cash crops. A classic example is using barley or other small grains to raise grain-specific aphids. These aphids, in turn, attract beneficial insects which can control populations of other types of "pest" aphids within the tunnel.

Cherish Your Spiders

Spiders consume twice their body weight every day. While spiders are indiscriminate eaters, investigators have found that at least 80% of their diet consists of pest insects. *(See "LeSar and Unzicker" article referenced on page 74.)* Spiders eat aphids, leafhoppers, whiteflies, and cucumber beetles, as well as many other pests, and their pheromones also scare off a lot of insects.

Habitat is important to spider survival. They need a hiding place during the day and in the winter, though they may overwinter in the soil. Easy-to-make spider condos consist four or five 6" long bamboo sections bundled together. To make a section, cut the bamboo so that it includes a node near one end. It should look like an upside down test tube or a pipe with a cork in it at the top. Wrap four or five of these together and place them near problem pest areas as needed. These can be suspended a couple inches off the ground attached to the inner cover support structure.

Glossary

Come-along. A hand operated geared rachetting device to pull heavy objects.

Drift punch. A tapered metal pin used to align holes, knock out bolts or other debris from holes.

Ground pipe, post, or pin. A pipe buried in the ground and attached to the bow to support the structure. It functions as an anchoring foundation member.

Haygrove. A company, based in the United Kingdom, that manufactures field scale tunnels, mobile livestock buildings and specialist horticultural machinery. They manufacture multi-bay high tunnels.

PEX. Cross-linked high-density polyethylene used as tubing in radiant heating systems.

Pike pole. A pole that has a natural or designed hook on one end that catches the bow and assists in pushing the bow, especially above one's reach.

Plumb. To make something perpendicular to the earth's surface using gravity (typically a string and heavy weight).

Purlin. Typically a horizontal length of swedged pipe attached at the ridge and points along the bow to add structural integrity and strength.

Spline. In high tunnel/greenhouse construction a spline is a short (approx. 12" to 18”) pipe used to join two similar diameter pipes, usually the bow and ground pin/pipe. The spline has a smaller outside diameter (O.D.) than the inside diameter (I.D.) of the two pipes it is joining. These pipes are commonly joined by tek screws or bolts.

Swedged pipe. 4" or 5” of one end of a pipe is rolled to a smaller diameter, allowing it to be inserted into the end of another pipe.

Truss. A structural member (pipe in high tunnels) connecting the bows and often the ridge purlin. It adds structural strength.

Resources

This list is not intended to be complete and does not comprise an endorsement of the companies listed. There are many other reputable manufacturers and distributors besides those listed below.

Greenhouse Structures

Also see "Multi-Bay Structures"

Ledgewood Farm Greenhouse Frames
Ed Person, owner
132 Old Mountain Rd.
Moultonborough, NH 03254
603/476-8829
ed@ledgewoodfarm.com
www.ledgewoodfarm.com
Manufactures pipe frame greenhouses and high tunnels. Ledgewood frames are used in all areas of agriculture for plant protection, livestock housing, and storage. Why not buy from a fellow farmer who grows in the structures he sells!

Rimol Greenhouse Systems, Inc.
Bob Rimol
Northpoint Industrial Park
40 Londonderry Turnpike
Hooksett, NH 03106
877/746-6544, 603/629-9004
www.rimol.com/agricultural.asp
A newer manufacturer of greenhouses; shade structures and related systems, serving primarily small and medium-size businesses. Many different options available for heating, cooling. environmental control, irrigation, and crop support systems. Strong customer support includes prompt delivery, outstanding directions, and availability of experienced staff to answer questions. All greenhouses are designed for heavy snow and wind loads.

Harnois Industries
1044 Principale C.P. 150
St-Thomas (Joliette)
Quebec, Canada, JOK 3LO
888/427-6647
www.harnois.com
A leading greenhouse structures and equipment manufacturer, their extensive line of greenhouses includes gutter connects and a unique vent ridge system. Their freestanding 40' OIvaltech has 10' high roll-up sides for maximum ventilation and natural light.

Atlas Greenhouse Systems
9596 US Hwy 82 East, P.O. Box 558
Alapaha, GA 31622
800/346-9902, 229/532-2905
Fax 229/532-4600
service@atlasgreenhouse.com
www.atlasgreenhouse.com/cf.html
Manufacturer of agricultural, educational and hobby greenhouses and a large supplier of greenhouse equipment for the commercial greenhouse grower. Freestanding and gutter connected greenhouses as well as cold frames and shade structures to small or large size growers around the world. Atlas inventories a comprehensive selection of heaters, fans, coverings, ground fabrics, shade cloth, doors, and many other specialized items in our own warehouse ready for immediate shipping.

Griffin Greenhouse & Nursery Supply
1619 Main Street, P.O. Box 36
Tewksbury, MA 01876 (corporate office)
978/851-4346
www.griffins.com
Regional offices:
Auburn, NY 315/255-1450
Brookhaven, NY 631/286-8200
Bridgeton, NJ 856/451-5170
Cheshire, CT 203/699-0919
Ewing, NJ 609/530-9120
Latham, NY 518/786-3500
Morgantown, PA 610/286-0046
Gray, ME 207/657-5442
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Growell Greenhouses
Mike Tripedino, owner
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Greenhouse and solarium builders and distributor of greenhouses equipment and supplies. Mike is helpful and willing to walk you through putting up your own house. He will also send crews to erect houses and re-cover them.

Nexus Corporation
10983 Leroy Drive
Northglenn, CO 80233
800/228-9639, 303/457-9199
Fax 303/457-2801
www.nexuscorp.com
Serving commercial greenhouse growers for over 35 years with a broad range of greenhouse structures and excellent customer service. All their structures can be customized for the size, covering, heating, cooling, and controls.

XS Smith
Corporate Headquarters
932 Page Rd.
Washington, NC 27889
800/631-2226
Also 1602 Lawrence Ave., Suite 103
Ocean, NJ 07712
732/643-0433
Fax 732/643-0699
info@xssmith.com
sales@xssmith.com
Manufacturer of greenhouse structures and horticultural products since 1946. Wide line of greenhouses from small ground-to-ground Quonset structures to multi-span gutter-connected complexes.

W. H. Milikowski, Inc.
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Stafford Springs, CT 06076
860/684-1595, 800/243-7170

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Full-line greenhouse and nursery supplier, including a range of structures made by Star Steel, an affiliate. Serves New England and adjacent region with warehouses in CT, NJ, and Syracuse, NY.

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Wadsworth, OH 44281
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techsupport@cropking.com
www.cropking.com
A 23-year-old company specializing in controlled environment agriculture and hydroponics, CropKing is a manufacturer, importer, and distributor of commercial facility structures, hydroponic growing systems, supplies, and equipment, in North America and the Caribbean.

Multi-Bay Tunnels

Haygrove Tunnels
Ralph Cramer (East Coast Contact)
116 Trail Road North
Elizabethtown, PA 17022
866-HAYGROVE
ralph.cramer@haygrove.com
www.haygrove.com
Also see www.haygrove.co.uk
World leaders in the design and manufacture of field scale tunnels, mobile livestock buildings and specialist horticultural machinery. Haygrove are growers based in Herefordshire in the United Kingdom.

Greenhouse Supplies and Plastic Disposal

(Plastic film, row cover, plastic disposal, greenhouse supplies, irrigation supplies)

Plastic Film

Farm Tek
1440 Field of Dreams Way
Dyersville, IA 52040
800/327-6835, Fax 800/457-8887
www.farmtek.com
Commercial greenhouses and supplies, tension fabric buildings, range farm products, etc.

Green.Tek, Inc.
417 East Fulton Street
Edgerton, WI 53534
800/747-6440, Fax 608/884-9459
info@green-tek.com
www.green-tek.com
Green-Tek is a leading converter and fabricator of plastic coverings for the greenhouse and architectural glazing industries. Products include polycarbonate multiwall and corrugated sheeting, poly films, and shade cloth.

Klerks Plastics Products
546 L&C Distribution Park
Richburg, S.C. 29729
888/255-3757, Fax 803/789-4001
www.klerksusa.com/products
Klerks is a global supplier of high quality plastic products for horticulture and agriculture. Some of its breakthroughs in greenhouse films are KoolLite 380 and advanced long-lasting anti-condensation films. KoolLite 380 selectively filters the light spectrum, giving growers the highest quality of PAR light available.

Northern Greenhouse Sales
Box 42, Neche, ND 58265
204/327-5540
www.northerngreenhouse.com
Various thicknesses of CLEAR (and colored) Superstrong Woven Poly for greenhouses, barn curtains, etc.

Recoltech
519 Notre-dame St
Rémi, Québec, Canada J0L 2L0
450/454-6996, 877/254-6996
Fax 450/454-7167
info@recoltech.com
www.recoltech.com
Plastic mulches, floating row covers, drip and other irrigation equipment. Primarily a French speaking company.

Row Cover

American AgriFabrics
1282 Old Alpharetta Rd.
Alpharetta, GA 30005
800/565-5151, 770/663-7600
Retailer and wholesaler of AgroFabric Reemay, landscape fabric, netting.

Dubois Agrinovation Inc.
478, Notre-Dame
Saint-Remi, Quebec, Canada J0L 2L0
450/454-3961, 800/667-6279
www.DuboisAg.com
Row cover, irrigation supplies, plastic mulch, bird netting, etc. Formerly "Plastitech."

Ken-Bar, Inc.
Summit Industrial Park
147 Summit St., Building 3D, Suite 3
Peabody, MA 01960
800/336-8882, 781/944-0003
Fax: 781/944-1055
info@ken-bar.com
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Row covers, pest management, tools, propagation supplies, etc. Distributes Tufbell, a hard-to-find, expensive but extremely durable row cover made of polyvinyl alcohol. Online catalog.

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The Suntex agricultural line includes Covertan Pro non-woven row covers & Agro Poly Embossed Mulch Films. Covertan Pro is transparent, and air and water permeable, assuring unifiorm heat and moisture exchange.

Plastic Disposal

Daniel Zook
Zook Plastic Recovery
183 South Farmersville Rd.
Leola, PA 17540
717/656-4422
Call for collection schedule. Mr. Zook is now paying up to $80 - $100 for clean greenhouse film. Highest prices are during his seasonal drives.

Karen Kritz
Agricultural Economic Development
Division of Marketing & Development
NJ Department of Agriculture
PO Box 330, Trenton, NJ 08625-0330
609/984-2506, Fax 609/341-3212
karen.kritz@ag.state.nj.us
www.nj.gov/agriculture/divisions/md/prog/recycling.html
Ms. Kritz is the recycling maven who initiated NJ's horticultural film recycling programs.

Cumberland County Improvement Authority
Dennis DeMatte, Recycling Coordinator
2 North High St.
Millville, NJ 08332
856/825-3700
ccia@ccia-net.com
www.ccia-net.com
A recycling collection and marketing program for horticultural film and other materials in southern NJ. Procedures for preparing plastic film for recycling downloadable from website. Out of state materials accepted.

Trex Company
Andrea Dahl
160 Exeter Dr., Winchester, VA 22603
800/289-8739, 540/542-6300,
adahl@trex.com
Ms. Dahl can assist entrepreneurs in creating collection programs for agricultural plastic films. Clear, clean plastic films are preferred.

For more background and resources on agricultural plastic recycling, visit: environmentalrisk.cornell.edu/AgPlastics

Greenhouse Supplies

Hydro-Gardens, Inc.
P.O. Box 25845
Colorado Springs CO 80936
800/634-6362
hgi@hydro-gardens.com
www.hydro-gardens.com
Since 1968, a specialist in hydroponics. Greenhouse supplies, organic fertilizers, pest management supplies, beneficial insects, books, seeds, irrigation equipment, general supplies.

International Technology Services
P.O. Box 75
Lafayette, CO 80026
800/375-1684
rghome@ intertechserv.com
www.greenhouseinfo.com
Serving conventional and organic growers for over 20 years. Beneficial insects, pest trapping and monitoring supplies, pest identification guides, bumblebees form pollination, fertilizers and fertilizer injection systems, biological and botanical pesticides, polypropylene ground covers, etc.

K.C. Schaefer Supply Co. Inc
2655 Springwood Rd.
York, PA 17402
717/741-5088, Fax 717/741-5089
www.schaefer-hort.com
Wholesales farm supplies.

Nolts Produce Supply
152 N. Hersey Ave.
Leola, PA 17540
717/656-9764
Very good, reliable source of agricultural supplies.

Silver Creek Supply
5656 S. Susquehanna Trail
Port Trevorton, PA 17864
570/374-8010, Fax 570/374-8071
silcreek@mail.uplink.net
www.silvercreeksupply.net
Greenhouse, lawn and garden, and nursery supplies, including seeds, irrigation products, fertilizers, and mulch plastics.

Wetsel Growers Supply
P.O. Box 791
961 North Liberty Street
Harrisonburg, VA 22801
540/434-6753, 800/572-4018
Fax 540/434-4894
wetsel@shentel.net
www.wetsel.com
Wetsel's commercial grower department supplies greenhouse frames and skins, environmental

systems, watering and irrigation systems, and other items.

Irrigation

Also see "Nolts Produce Supply" under "Greenhouse Supplies."

Charles W. Harris Company, Inc.
Jim Peeler, owner
New address: 72 Tower Hill Rd.
Brimfield, MA 01010
888/928-3731
Full line of agricultural irrigation equipment and supplies.

DripWorks, Inc.
190 Sanhedrin Circle
Willits, CA 95490
800/522-3747
Design & Tech Support 707/459-6323
Fax: 707/459-9645
sales@dripworksusa.com
design@dripworksusa.com
www.dripworksusa.com
Quality drip irrigation and micro irrigation supplies for home owners, landscapers, farmers and greenhouse owners. Drip emitters, micro sprayers, emitter tubing, T-Tape® drip tape, misters, timers, filters, etc. Their on-line store has complete product line with product descriptions.

International Irrigation Systems - Irrigro
P.O. Box 163, 1755 Factory Outlet Blvd.
Niagara Falls, NY 14304-0163
877/477-4476 (IRRIGRO)
905/688-4090
Fax 905/688-4093
sales@irrigro.com
www.irrigro.com
Equipment and supplies for the watering needs of commercial growers and home gardeners worldwide. With over 20 years of manufacturing and field experience, Irrigro has made significant technological breakthroughs (such as super-strength seals, pressure compensating flow controllers, and subsurface conduit).

Netafim USA
Drip Irrigation Solutions
5470 E. Home Ave.
Fresno, CA 93727
888/NETAFIM, 559/453-6800
Fax 800-695-4753
www.netafimusa.com
Full range of drip and micro-irrigation products and technical support. Since 1965.

Rain-Flo Irrigation
884 Center Church Rd.
East Earl, PA 17519
717/445-6976
Leading manufacturers of plastic laying and removing machinery, water-wheel transplanters and suppliers of plastic mulches, irrigation equipment including drip, overhead pipes, and pumps and floating row covers.

Trickle-eez Company
Sales Offices:
4266 Hollywood Rd.
St. Joseph, Michigan 49085
800/874-2553, 269/429-8200
Fax 269/429-6669
3550 Chambersburg Rd.
Biglerville, PA 17307
800/672-4700, 717/337-3030
Fax 717/337-1785
info@trickl-eez.com
www.trickl-eez.com
A leading dealer in drip irrigation, and other types of irrigation systems for over 25 years.

Monitoring and Testing Equipment

Gempler's
P.O. Box 44993
Madison, WI 53744-4993
800/382-8473
customerservice@gemplers.com
www.gemplers.com
Gempler's carries many soil sampling supplies including pH kits, nitrate testing kits, soil sampling devices including soil probes and soil compaction testers, and many other sampling tools. Also suppliers of protective equipment and supplies for agricultural production, maintenance, etc.

Timberleaf Soil Testing
39648 Old Spring Rd.
Murrieta, CA 92563-5566
951/677-7510
tmbrlfsoiltest@verizon.net
The Timberleaf soil test was developed especially for market gardeners who practice the biointensive approach. The basic soil test includes base saturation/CEC, estimated nitrogen release, available nutrients, pH, and soluble salts. Optional tests exist for organic matter, trace minerals, and composts/ greenhouse media. The detailed soil test report contains the test results and explanations, and organic fertilization recommendations.

Also for General Agriculture:

Ben Meadows Company
P.O. Box 5277
Janesville WI 53547-5277
800/241-6401, Fax 800/628-2068
www.benmeadows.com
An extensive line of soil testing supplies includes electrical conductivity meters (starting at $100), penetrometers, shear tester, soil charts, soil educational kits, soil testing meters, tensiometers and irrometers, test kits and strips, tile probes, auger kits, rotary hammer kits, sieves, and accessories.

More Scientific:

Cole-Parmer
625 Bunker Court
Vernnon Hills, IL 60061
800/323-4340, Fax 847/247-2929
info@Coleparmer.com
www.coleparmer.com
Specialized equipment for monitoring plant nutrition and soil nutrient levels. Extensive list at their website.

Pike Agri-Lab Supplies
154 Claybrook Rd.
Jay, ME 04239

207/897-9267, Fax 207/897-9268
info@pikeagri.com
www.pikeagri.com
This family-run business provides test kits and monitoring instruments to assist farmers and composters and promote biological agriculture. Pike Agri-Lab also develops and manufactures tools in Maine and can help farmers set up their own test labs, for performing quick, simple tests in the field. Operating since 1977. Pike Agri-Lab sells a combination pH and soil salts (electrical conductivity) meter for $144.

Beneficial Insects (Suppliers)

IPM Labs. Inc.
P.O. Box 300
Locke, NY 13092-0300
315/497-2063
ipmlabs@baldcom.net
www.ipmlabs.com
IPM Labs supplies beneficial organisms for the biological control of pests and provides support to facilitate their successful use. They produce 7 species of beneficial organisms and distribute more than 45 other species.

Great Lakes IPM
10220 Church Rd., NE
Vestaburg, MI 48891
989/268-5693, 989/268-5911, or
800/235-0285, Fax 989/268-5311
glipm@nethawk.com
www.greatlakesipm.com
Insect monitoring systems for the professional grower. Suppliers of pheromone lures, insect traps, visual traps, insect sweep nets, ground cloths, bird netting, trapping adhesives, soil probes, grain probes and thermometers, beneficial insects and other insect supplies.

Rincon-Vitova Insectaries Inc.
P.O. Box 95
Oak View, CA 93022
800/248-2847
www.rinconvitova.com
RVI produces and distributes insects and other organisms, supplies and tools for biological control of pests. Safe alternatives to microbes "from insects to microbes." Biological control programs use predators, parasites, pathogens and antagonists and build on active beneficial microbes in soil. Sole distributor for D-Vac vacuum insect sampling equipment.

The Green Spot Ltd.
93 Priest Rd.
Nottingham, NH 03290-6204
603/942-8925,
www.greenmethods.com
Suppliers of biological control organisms and excellent information on individual bio control agents.

Beneficial Insects (Organizations)

Pennsylvania Integrated Pest Management Program
Cathy Thomas, Coordinator
PA Dept. of Agriculture
Bureau of Plant Industry
2301 North Cameron Street
Harrisburg, PA 17110-9408
717/772-5204
caththomas@state.pa.us
paipm.cas.psu.edu/green/greenhouse.html
A highly recommended resource.

IPM Program—NYS Agricultural Experiment Station
P.O. Box 462
Geneva, NY 14456
315/787-2432, 800/635-8356
Fax 315/787-2360
www.nysipm.cornell.edu
www.nysaes.cornell.edu/recommends
The New York State Integrated Pest Management Program develops sustainable ways to manage pests and helps people to use methods that minimize environmental, health, and economic risks.

Biointensive Agriculture

Ecology Action
5798 Ridgewood Rd
Willits, CA 95490
707/459-0150
www.growbiointensive.org
For the past 31 years, Ecology Action has been researching, developing and sharing millennial-old techniques for growing more food in a small area, using simple tools and seeds, while maintaining or increasing the health and productivity of the soil.

Seeds and General Farm Supplies

Johnny's Selected Seeds
955 Benton Ave.
Winslow, ME 04901
877/564-6697, Fax 800/738-6314
rstore@johnnyseeds.com
www.johnnyseeds.com
Quality vegetable, herb, and flower seeds and tools, equipment, and supplies to critical home gardeners and small commercial growers. An independent company since 1973 and employee owned since 2006. All of Johnny's seeds and accessories are tested at the company's certified organic farm in Albion, ME.

Fedco Seeds
P.O. Box 520
Waterville, ME 04903-0520
207/873-7333
www.fedcoseeds.com
A source for cold-hardy selections (seeds, tubers, trees, and bulbs) adapted to the Northeast climate as well as a large selection of certified organic cultivars and regional heirloom varieties. Fedco's product lines (including organic growers supply) and cultural hints encourage sustainable growing methods. Three free catalogs annually. Mail order, fax and internet orders only except during designated pickup. No phone orders.

Germania Seed Company
5978 North Northwest Hwy.
P.O. Box 31787, Chicago, IL 60631
800/380-4721, 773/621-6631
Fax 800-410-4721
www.germaniaseed.com
Since 1932. Specialist in flowers. Distributes annual, perennial and vegetable seeds, plants, and plugs.

High Mowing Seeds
76 Quarry Rd.
Wolcott, VT 05680
802/472-6174, Fax 802/472-3201
www.highmowingseeds.com
This small, family-owned, certified organic seed company located in Northern Vermont ships across the U.S. to customers who value organic seeds, sustainable agriculture, and good service.

Wild Garden Seed
P.O. Box 1509
Philomath. OR 97370
541/929-4068
www.wildgardenseed.com
This organic seed and vegetable farm in the Pacific Northwest produces farm-original varieties of many salad greens, vegetables, herbs and a few flowers. All seed is open pollinated, untreated, germ and vigor tested in living soil mix, and well cleaned.

Bountiful Gardens
18001 Shafer Ranch Rd .
Willits CA 95490
707/459 6410, Fax 707/459 1925
bountiful@sonic.net
www.bountifulgardens.org
Untreated open-pollinated seed of heirloom quality for vegetables, herbs, flowers, grains, green manures, compost and carbon crops. Rare and unusual varieties, medicinal herbs, super-nutrition varieties. Also biointensive books/videos for growing soil sustainably using mini-farming techniques such as double-digging, intensive spacing, and companion planting. Fine tools, basic organic gardening supplies, and non-toxic insect controls.

Peaceful Valley Farm Supply
(See Row Cover listing)

Miscellaneous Supplies

Surplus Center
P.O. Box 82209
Lincoln, NE 68501
800/488-3407, Fax 402/474-5198
customerservice1@surpluscenter.com
www.surpluscenter.com
Surplus Center is a warehouse distributor for many name brand manufacturers, such as Parker Hydraulics, Hypro Pumps, Chief Hydraulics, and Prince Hydraulics. It also offers low wattage 12 volt DC blowers for inflating high tunnel plastic using solar power. Many other products.

Tools

CSA Works
Michael Docter
Hadley, MA
foodbankfarm@yahoo.com
Parts and planting guide for Planet Jr. seeders.

Johnny's Selected Seeds
(See Seed listing)
Carries hard-to-find market gardener tools that are useful for intensive cultivation in high tunnels. Precision seeders (pinpoint and other models), collinear hoes, broadfork, bed preparation rake, etc.

Peter B. Johnson
7967 Ft. Loudon Rd.
Mercersburg, PA 17236
717/328-4857
lpjohnson@innernet.net
U-bar for bio-intensive agriculture handmade by a family business.

Market Farm Implement
257 Fawn Hollow Rd.
Friedens, PA 15541
814/443-1931
www.marketfarm.com
Vegetable crop machinery from tillage to harvest. Sells Cole Planet Jr. (over $500 per row).

Roeters Farm Equipment
565 120th St.
Grant, MI 49327
231/834-7888
www.roetersfarmequipment.com
New and used vegetable equipment, including vintage Planet Jr. seeders.

Further Information and References

These references and resources are intended as a starting point for further reading. This list is by no means exhaustive or definitive. We acknowledge that some items may be outdated or difficult to find.

Agriculture Information Services

Appropriate Technology Transfer to Rural Areas (ATTRA)
P.O. Box 3657
Fayetteville. AR 72702
800/346-9140
www.attra.org
Free publications, information packets, and other technical assistance from the National Sustainable Agriculture Information Service. For farmers, extension personnel, educators, and others involved in sustainable agriculture. Created and managed by the National Center for Appropriate Technology (NCAT). Relevant publications include:

- *Greenhouse IPM: Sustainable Aphid Control*
- *Greenhouse IPM: Sustainable Thrips Control*
- *Greenhouse IPM: Sustainable Whitefly Control*
- *Root Zone Heating for Greenhouse Crops*
- *Season Extension Techniques for Market Gardeners*
- *Solar Greenhouses Resource List*

Organic Agriculture Information
www.organicaginfo.org
Frequently updated website with production information, economic data, research results, farmer anecdotes, certification information, transition strategies, and other subjects related to organic agriculture. Offered by the Organic Agriculture Consortium (OAC)/Scientific Congress on Organic Agricultural Research (SCOAR) and funded by a USDA grant.

National Agricultural Library
US Dept of Agriculture
10301 Baltimore Ave. Room 304
Beltsville MD 20705-2351
301/504 6559, Fax 301/504-6409
afsic@nal.usda.gov
www.nal.usda.gov
Two resources: AGRICOLA database and the Alternative Farming Systems Information Center, (www.nal.usda.gov/afsic)
AGRICOLA, one of the largest databases in the world, is a tremendous resource for academic information. NAL has one of the world's largest and most accessible agricultural information collections.

Periodicals

Growing for Market
PO Box 3747
Lawrence, KS 66046. 800/307-8949
growing4market@earthlink.net
www.growingformarket.com
(Monthly, $33) An informative, thoughtful magazine mostly written by farmers. Often has useful articles about growing winter greens. Supportive of organic, sustainable agriculture.

HortIdeas
750 Black Lick Rd.
Gravel Switch, KY 40328.
gwill@mis.net
users.mikrotec.com/~gwill/index.html
(Monthly, $25) Independent advertising-free gardening newsletter that abstracts new information from a wide range of sources relevant to horticulture. For over two decades.

Acres: A Voice for Eco-Agriculture
P.O. Box 91299
Austin, TX 78709
518/892-4400
info@acresusa.com
www.acresusa.com

The New Farm: Farmer-To-Farmer Know-How from the Rodale Institute
www.newfarm.org
A free electronic newsletter with searchable database.

Cold Stress Physiology

Levitt, J. Responses of Plants to Environmental Stress. Orlando, FL: Academic Press. 1980.

Environment

Thorton, PhD, Joe. *Environmental Impacts of Polyvinyl Chloride Building Materials*. A Healthy Building Network Report. 2002. 110 pp. (From the Institute for Local Self-Reliance, 202/232-4108, www.healthybuilding.net).

Fruit

Whitehead, William. Grow Fruit in Your Greenhouse. London, UK: Faber and Faber. 1970. 163 pp.

Gardening

Jeavons, John. How to Grow More Vegetables. 6th ed. Berkeley, CA: Ten Speed Press, 2002, 240 pp.

Wagenvoort, W.A. and Bierhuizen, J.F. *Some Aspects of Seed Germination in Vegetables*. Scientia Horticulturae. 6 (1977). 213-219.

General Greenhouse

Beckett, Kenneth A. Growing Under Glass. New York, New York: Simon and Schuster. 1981. 96 pp.

Bond, John. Handbook for Polytunnel Growing. Bristol, England. National Federation of City Farms. 1991. 20 pp.

Edey, Anna. Solviva: How to Grow $500,000 on One Acre and Peace on Earth. Martha's Vineyard, MA.: Trailblazer Press, 1998. 221 pp.

Grotzke, Hienz. Biodynamic Greenhouse Management. Biodynamic Farming and Gardening Association. 1998. 112 pp. $12. (25844 Butler Road, Junction City, OR 97448, 888/516-7797, www.biodynamics.com).

Mazria, Edward. The Passive Solar Energy Book. Emmaus, PA: Rodale Press. 1979. 435 pp.

McCullagh, James C., ed. The Solar Greenhouse Book. Emmaus, PA: Rodale Press, 1978, 328 pp.

Salt, Bernard. Gardening Under Plastic: How to Use Fleece, Films, Cloches and Polytunnels. London, UK: B.T. Batsford Ltd. 127 pp.

Smith, Shane. The Bountiful Solar Greenhouse; A Guide to Year-Round Food Production. Santa Fe, NM: John Muir Publications Inc. 1982. 221 pp.

Story, David. Plastic and Vegetables: A Guide to Organic Growing in Polytunnels. Dublin, Ireland: IOFGA (Irish Organic Farmers and Growers Association). 1993, 54 pp.

Stinson, Richard F. Greenhouse Crop Production, Student Manual. University Park, PA: PSU. 1983. 223 pp.

Taylor, T.M. Secrets to a Successful Greenhouse and Business. Melbourne, FL: Green Earth Publishing Co., Inc. 1999. 279 pp.

Greenhouse Design

Aldrich, Robert A. and Bartok, John W., Jr. Greenhouse Engineering. Ithaca, NY: Northeast Regional Agricultural Engineering Service (NRAES, Cooperative Extension, PO Box 4557, Ithaca, NY 14852-4557, 607/255-7654, nraes@cornell.edu, www.nraes.org). Revised ed. NRAES-133. 212 pp. $30.

Bartok, John W., Jr. Energy Conservation for Commercial Greenhouses. Ithaca, NY: NRAES. Revised ed. 2001. NRAES-3. 84 pp. $17.

Bartok, John W., Jr. Greenhouses for Homeowners and Gardeners. Ithaca, NY: NRAES. 2000. NRAES-137. 200 pp. $30.

Bartok, John W., Jr. Retractable Roof Greenhouses and Shadehouses. Factsheet. Available at: www.hort.uconn.edu/Ipm/greenhs/bartok/htms/retractableroofgreenhouses.htm.

Mazria, Edward. The Passive Solar Energy Book. Emmaus, PA: Rodale Press. 1979. 435 pp.

Greenhouse Plans

Sunspace & Solar Greenhouse Plan
Brace Research Institute
Publication Dept., Faculty of Engineering, P.O. Box 900
MacDonald College of McGill University
Ste. Anne de Bellevue, Quebec, H9X 3V9, Canada
514/398-7833, Fax 514/398-7767
ae12000@musica.mcgill.ca

Solstice Publications/Domestic Technologies Inc.
P.O. Box 2043
Evergreen, CO 80439
303/674-7700, Fax 303/674-7772
dri@domtech.com
A source for finding and purchasing articles, books, and reports on sunspaces and solar greenhouses.

Also see:
www.healthgoods.com/education/healthy_home_information/Building_Design_and_Construction/reading_sunspaces_greenhouses.htm

High Tunnel & Season Extension Publications

Coleman, Eliot. The New Organic Grower's Four-Season Harvest. White River Junction, VT: Chelsea Green Publishing Co. 1992. 212 pp.

Coleman, Eliot. The Winter Harvest Manual: Farming the Backside of the Calendar. Four Season Farm, 609 Weir Cove Rd., Harborside, ME 04642. 1998. 57 pp. Order from Fedco, *Growing for Market*, or directly from Eliot at above address.

Dreer, Henry A. Vegetables Under Glass. Henry A. Dreer, 714 Chestnut St., Philadelphia, PA. 2nd ed. 1896. 105pp.

Gerst, Jean-Jacques. Growing Vegetable Crops Under Direct Covers. Paris, France: Centre Technique Interprofessionnel des Fruits and Legumes. 1987. 165 pp.

Byczynski, Lynn, ed., The Hoophouse Handbook: Growing Produce and Flowers in Hoophouses and High Tunnels. Lawrence, KS: *Growing for Market*. 60 pp. $15. 800/307-8949.

Jett, Lewis. High Tunnel Tomato Production Guide (Publication M170). University of Missouri. Details about building a hoop house, with many photos, plus tomato production

information including color photos of insects, disease, and physiological disorders. 28 pp. $10. From MU Ext. Publications, 800/292-0969, muextension.missouri.edu/explore/manuals/m170.htm

Janick, Jules and Swaim, David. Development of an Innovative Production and Marketing System for Specialty Vegetables. Final Report. No date. Purdue University. www.hort.purdue.edu/newcrop/hfresh/finalreport.pdf

Lamont, Bill and Orzolek, Mike. High Tunnel Production Manual 2003. Over 150 pp. $26.50 payable to Penn State University. Mail payment to Dr. Bill Lamont, Dept. of Horticulture, 206 Tyson Building, Penn State University, University Park, PA 16802.

Poisson, Leandre and Gretchen. Solar Gardening. White River Junction, VT: Chelsea Green Publishing Co. 1994. 267 pp.

Wiediger, Alison and Paul. Walking to Spring: Using High Tunnels to Grow Produce 52 Weeks a Year. From Au Naturel Farm, 3298 Fairview Church Road, Smiths Grove, KY 42171. $15 plus $3.50 S/H or from *Growing for Market*.

High Tunnel Research, Education and Websites

Connecticut
Martin Gent
Dept. of Forestry and Horticulture
Connecticut Agricultural Experiment Station
203/974-8489,
Martin.Gent@po.state.ct.us
Physiology of high tunnel crops – growth, yield, nutrients, environment

Kansas, Missouri, and Nebraska
www.hightunnels.org
High Tunnel Team of Central Great Plains

Michigan
John Biernbaum
Michigan State University Dept of Horticulture
517/355-5191 x419
biernbau@msu.edu
Winter growing in unheated tunnel research since 2001. Also 48-week CSA at student organic farm
New interactive online course in 2007: Passive Solar Greenhouses for Protected Cultivation (credit and non-credit enrollment options). Future courses on compost and organic transplants.

Maine
Barbara Murphy
University of Maine Cooperative Extension, Oxford County
207/743-6329
bmurphy@umext.maine.edu
Comparison of cut flower production in field and in high tunnel, including season extension.

Gleason Gray
University of Maine Cooperative Extension, Penobscot County
207/942-7396
ggray@umext.maine.edu
Active solar heating in a high tunnel for spring and fall season extension. Experimental design includes black tubing containing circulating water mounted on bows, flexible tubing buried 6" deep, and a buried 5,000 gallon storage tank.

New Jersey
Rutgers University High Tunnel Project. See archived reports at: aesop.rutgers.edu/~horteng/HighTunnels/HighTunnels2005.pdf

New York
Marvin Pritts
Cornell Dept. of Horticulture
607/255-1778
mpp3@cornell.edu
Small fruit in high tunnels – raspberries, strawberries, etc.

Reid, Judson
Cornell Vegetable Program
315/536-5123
jer11@cornell.edu
Tomato, cucumbers, peppers and cover crops variety trials in high tunnels.

Stephen Reiners
Dept. of Horticultural Sciences, NYS Ag Experiment Station
315/787-2311
sr43@cornell.edu
General vegetable culture, soil fertility.

Chris Wien
Dept. of Horticulture, Cornell University
607/255-4570
hcw2@cornell.edu
Season extension in cut flowers, day length considerations in manipulating time of bloom.

Ohio
Ron Becker
Ag & IPM, Ohio State University Extension, Wayne County
330/264-8722
becker.4@cfaes.osu.edu
Implementation of Integrated Pest Management practices in high tunnels.

Brad Bergefurd
Ohio State University South Centers
740/289-2071 x136
bergefurd.1@osu.edu
http://southcenters.osu.edu/hort/
High tunnel strawberries, tomatoes, and moveable tunnel structures – research, extension, on-farm demonstrations.

Matt Kleinhenz
Dept. of Horticulture and Crop Science, Ohio Agricultural Research and Development Center
330/263-3810
kleinhenz.1@osu.edu
High tunnel design, use in conventional and organic systems, cultural practices and product quality.

Pennsylvania
Center for Plasticulture, Penn State University
http://plasticulture.cas.psu.edu
Research, events, experimental results, etc.

Insects (Beneficial and Pest)

Carr, Anna. Rodale's Color Handbook of Garden Insects. Emmaus, PA: Rodale Press. 1979, 241 pp.

Casey, Christine, ed. Integrated Pest Management for Bedding Plants. Ithaca, NY: Cornell University Press. 1999. 117 pp. $14.50

Cherim, Michael S. The Green Methods Manual. Nottngham, NH: The Green Spot Publishing, Ltd. 1998. 238 pp.

Flint, Mary Louise and Dreistadt, Steve H. Natural Enemies Handbook: The Illustrated Guide To Biological Pest Control (Pub. 3386). Oakland CA: U. of CA, Div. of Agriculture and Natural Resources Communication Services. 1998. 154 pp.

Gill, Stanton and Sanderson, John. The Ball Identification Guide to Greenhouse Pests and Beneficials. Batavia, IL: Ball Publishing. 1998. 244 pp.

Howard, R.J., Garland, J.A., and Seaman, W.L. Diseases and Pests of Vegetable Crops in Canada. Societe d'entomologie du Canada, 393 Winston Avenue, Ottawa, ONT, Canada K2A lY8. (613/725-2519) ISBN 0-9691627-3-1 (soft and hard cover, English and French).

Jordan, William H. Jr. Windowsill Ecology: Controlling Indoor Plants With Beneficial Insects. Emmaus, PA: Rodale Press. 1977. 229 pp.

Koppert Biological Sysems. Koppert Side Effects Database: Side Effects of Pesticides on Beneficial Organisms. www.koppert.nl/e0110.html

LeSar, Charles D. and Unzicker, John D. *Life History, Habits and Prey Preferences of Tetragnatha laboriosa*. 1978. Environmental Entomology: 7.

Scopes, Nigel E.A. and Ledieu, Michael S. Integrated Control of Tomato Pests (Growers Bulletin No. 3). Littlehampton, West Sussex, England: Glasshouse Crops Research Institute. 1979. 28 pp.

Thomas, Cathy and the Pennsylvania IPM Program. Greenhouse IPM with an Emphasis on Biocontrols. Penn State University. Based on Bug vs. Bug article series. 108 pp. Over 90 full-color images.
Download free PDF file from
http://paipm.cas.psu.edu/ghmanual.htm
Or send check or money order for hard copy ($12 plus $5 S/H per order) to Publications Distribution Center, PSU, College of Ag. Sci., 112 Ag.Admin. Building, University Park, PA 16802-2602. Credit card orders, 877/345-0691.

Nitrates

Affleck, Elisabeth A. Nitrate Levels in Greenhouse Grown Salad Mix: A Case Study of Three Sisters Bioshelter, (unpublished). Dept. of Parks and Recreation, Slippery Rock University, Slippery Rock, PA. May 1998. 48 pp.

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Vegetable Production Budgets for a High Tunnel

Resource 010 Back to My Spot

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Introduction

High tunnels, also referred to as "hoop houses," are simple, plastic-covered, passive solar-heated structures in which crops are grown in the ground. They have become an important tool in commercial vegetable and small fruit production in the Midwest. High tunnels enable growers to increase their profitability in several ways:

- They extend the growing season in the spring and fall allowing earlier and later production of cool and warm-season crops.
- Crop quality and yields can be improved through better climate, water, and nutrient management and a reduced incidence of plant diseases.
- They allow for better labor efficiency because planting, maintenance, and harvest can be performed without being affected by weather.
- Growers often receive higher prices for out-of-season crops.

Season Extension

Extending the season four or more weeks earlier in the spring and six or more weeks in the fall creates production opportunities in a high tunnel that field production may not. For example, late season production of leafy greens, which tolerate cooler temperatures and reduced day length, can extend your market season and increase revenue and profitability.

Early production of crops before the beginning of average market season not only strengthens your customer base, but the early crops typically command a higher price at the market place.

Growers say high tunnels create an environment one hardiness zone warmer than the field. This not only allows growers to produce crops earlier, but also allows growers to produce greater yields and improved quality of high value crops such as blackberries and red raspberries because they have fewer disease problems and are not subjected to late spring cold temperatures, hail, and high wind.

Crops and Cropping Systems

Although almost anything can be grown in a high tunnel, the crops you grow and the cropping systems you use should be determined by your market needs, available labor, and what is profitable for you. The advantages of growing crops in high tunnels make the limited space in the high tunnel valuable farm "real estate." It is important for growers to maintain good production and market records to make informed decisions about how to maximize production and revenue. For example, a mono-crop system, such as only tomatoes, with succession plantings and different varieties for extended harvest, may be the most efficient, profitable system for wholesale markets, such as institutions and grocery stores that require large, continuous volumes of a particular crop.

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A multi-crop system may be necessary if you market through farmer's markets, roadside stands, or Community Supported Agriculture (CSA) and need a variety of produce items, but not particularly in large quantities.

By optimizing the use of the space in the high tunnel through succession planting and intercropping, a grower can maintain continuous production throughout the market and CSA distribution season. These planting systems may improve productivity in a high tunnel with more than 100 percent of the area used for crop production in a growing season.

High tunnels are a benefit to growers who market their crops through shares in CSA. Since the crops are all pre-sold and there are no market variables, the specific amount of crop needed can be planted and timed so one crop is completely harvested and another one is planted in that area for later production. The high tunnel also provides some assurance to CSA growers that they will have a crop for their pre-paid customers. An Iowa CSA vegetable grower said that one year her high tunnel saved her spring CSA because the early crops in the field failed due to a late, cold, wet spring.

Succession planting for extended harvest periods can be accomplished in three ways.

1. After one crop is harvested, another is planted in the same space. For example, a cool season crop could be followed by a warm season crop.
2. The same crop is planted at timed intervals so they mature at different times.
3. Varieties of the same crop with different maturity dates are planted at the same time.

Intercropping is when a crop of a fast-maturing crop, such as lettuce, is planted between rows of a slower-maturing crop, such as tomatoes or peppers. The lettuce is harvested before the larger, later maturing crop requires that space.

Enterprise Budget

The enterprise budgets included in this publication are intended to be used as examples. They can help vegetable growers **estimate** the costs and returns to produce a crop or crops in their high tunnel. Enterprise budgets for a high tunnel can help growers allocate valuable space, labor, and capital to the most appropriate use. The most appropriate use may be to maximize profits, meet customer needs, or any other goal defined by the grower.

The estimated costs and returns presented in this publication are based on farm data received from five high tunnels on different farms between April and October in a single growing season. The original farm-derived budgets were adjusted slightly to make them more uniform with respect to ownership and fertilizer costs and other inputs and expenses. Because the high tunnels in the study varied in size, the budgets were developed on a per square foot basis. The various planting and cropping systems in a high tunnel, planting seasons, and management strategies used by the growers, also resulted in a wide range of profit potential. The examples given show a profit potential if the entire marketable crop is sold. It does not reflect losses incurred due to unsold products. Also all products were sold at the average price listed.

Lastly, as expected, this study found that a moveable high tunnel was able to add available covered production space through the season as compared to fixed tunnels, resulting in increased profitability.

Budget Format and Assumptions

Enterprise budget formats vary in format. Some are complex. Others are quite simple. Note that the budgets included in this publication are divided into four sections. The first section indicates the crop or crops budgeted, the size of the high tunnel, the approximate original cost, and the percent of the high tunnel utilized. Four enterprise budgets are illustrated in this publication; one multiple crop budget and three single crop budgets (bell peppers; thin-skinned, seedless cucumbers; and tomatoes).

The size of the high tunnel for all budgets was 30 ft. x 72 ft. or 2,160 square feet. The approximate original cost does not take into consideration any rebates or

cost-share programs. The percent utilization represents the amount of square footage planted and harvested as a percentage of the total square footage of the high tunnel. If multiple crops are planted and harvested within a single season (March – September on the same square footage area, it is possible to incur a utilization percentage greater than 100 percent. The 84 percent utilization for the multiple crop budget was close to the average of the five farms. It is assumed that a single crop enterprise would utilize all available space other than alleyways. For that reason, single crop enterprises were assumed to have a 94 percent utilization.

The second section illustrates the total receipts the high tunnel enterprise provides on a set unit(s). Records should be kept on both sales unit and land unit (square foot) basis. Prices for single crop budgets are assumed to reflect institutional or larger buyer prices (non-retail). The use of a single crop would indicate a larger supply available over a designated number of weeks. Prices for the multiple-crop budget were more reflective of a retail (direct-to-consumer) price. Yields were estimated based on what occurred on the five farms over an 8 to 12 week harvest period. The length of harvest was dependent upon the crop and variety. Not all crops were grown on all farms.

The third section is the cost of planting and growing the product. These costs are segmented for two reasons. First, these costs are incurred whether a product is sold or not. Once the seed is planted or watering is completed, it is a sunk cost and needs to be covered from some source. The second reason is the time delay between pre-harvest expenses and the time the product is sold. These expenses may have to be covered by borrowing, savings, or some other source. Estimated transplant and seed needs were based on a transplant price of $12 per 48 plants. Fertilizer expense was averaged over the five farms and came to $0.05 per square foot. Miscellaneous supplies were averaged over the five farms. An additional $50 was charged to the all-tunnel tomato enterprise to reflect additional costs for stakes and twine. Miscellaneous supplies do not take into account the initial costs of stakes, trellises, header lines, fitting, etc. Rather, they reflect a replacement value for those supplies. Water was charged at $0.04 per square foot and a water test was $17. Water estimates do not include any water usage fees charged by rural water companies or others. Irrigation supplies averaged $50 for the five farms. An additional charge of $72 was made to cover 6 hours of labor at $12 per hour to replace and/or fix any of the drip irrigation lines.

The fourth section is the labor component. Labor is divided into five activities: bed preparation, general maintenance (weeding, staking, pruning, etc.), planting, pest management, and harvest. Bed preparation time was less for single-crop enterprises. General maintenance, planting, and harvesting varied by the needs of the crop and were estimated based on what information was available from the five farms and experience. Labor wage rate was assumed to be $12 per hour. The wage rate does not include employment taxes, insurance, or other employee benefits.

The fifth section relates to the ownership costs. Each producer owns or controls assets that are used to produce the income, such as land, high tunnel, machinery, irrigation equipment, and other items. Ownership costs are an allocation to realize some return for the use of those assets. It is assumed that the high tunnel has an 8-year and the plastic covering a 4-year life span. The total ownership costs are estimated at approximately $0.46/square foot base on an approximate total high tunnel construction cost of $7,000 and a plastic cover replacement cost of $0.21 per square foot of tunnel ($454 for a 30 ft. x 72 ft. tunnel). Land rental and depreciation on machinery and equipment (tiller, plastic mulch layer, tractor, etc.) are not included.

The last section is the summary of total costs and returns. Total costs include the annual operating expenses (fertilizer, etc.), labor, and ownership. The return over total costs would be total receipts minus total costs. Annual returns can be analyzed as an overall number or by the square foot. Because space is a constraint in a high tunnel (there is only so much room), it makes sense to review annual returns using both units. Annual returns over total costs varied substantially by farm and enterprise. The differences in annual returns were influenced by a variety of factors. First, the annual return over total cost differed substantially by individual crop. Tomatoes, lettuce, herbs, and eggplant resulted in a much higher return than cucumbers (thin-skinned, seedless varieties) and bell peppers (see the multi-crop enterprise budget example).

Second, the annual return over total cost varied among producers. Yields received by producers varied based upon experience with certain crops and the varieties chosen. Third, overall profitability of the high tunnel varied substantially by the percent utilization. Overall, the potential annual returns for a high tunnel (excluding marketing costs) based on the findings of the five farms would indicate that a multi-crop or tomato high tunnel enterprise could be approximately $3.00 per square foot or $6,480 for a 2,160 square foot tunnel (30 ft. x 72 ft.). Assuming an initial investment of around $7,000, this level of return would indicate about a 1-year payback, which is unusual in agriculture.

Limitations

The illustrated budgets are to be used as an indication of what a particular crop could average over time and location. Individual farm results will vary from these numbers based on crop varieties selected, location to markets, and managerial ability, among other considerations. Note the budgets include receipts but not the costs associated with handling and marketing.

Post-harvest handling of high tunnel crops is often done at the same time as field-harvested crops and thus the cost cannot accurately be traced. Also, marketing costs vary tremendously based on whether products are distributed through a CSA, wholesaler, or direct through a farmer's market or other outlet. For this reason, they have not been included in the budgets. Marketing costs should, however, be included to determine crop profitability because, in some cases, costs can shift annual returns from a positive to a negative number.

Prepared by Craig Chase, farm management field specialist, and Linda Naeve, program specialist, Value Added Agriculture Program, Iowa State University Extension and Outreach.

Special thanks to the five farmers who kept detailed production records for this project.

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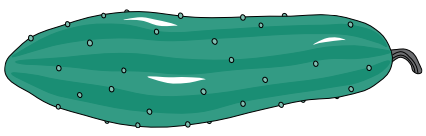

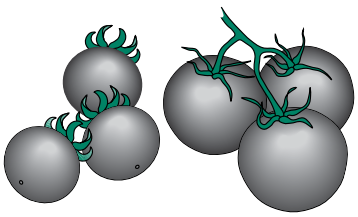

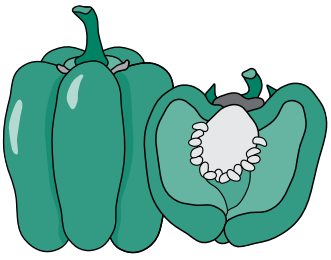

Iowa Multiple Product Vegetable Farm Budget Example

High Tunnel Size (sq. ft.) (30 x 72)	2,160 ft.
Utilization	84%
Approximate Original High Tunnel Cost	$7,000.00

Receipts	Yield	Sq. Ft.	$/Lb.	Total	Yield Per Sq. Ft.	Gross Per Sq. Ft.
Cucumbers	567.0	454	2.00	$1,134.00	1.25	$2.50
Eggplant	204.1	45	2.00	408.24	4.50	$9.00
Greens	166.9	363	7.00	1,168.47	0.46	$3.22
Herbs	14.5	9	16.00	232.24	1.60	$25.60
Lettuce	208.7	181	7.00	1,460.59	1.15	$8.05
Peppers - Bell	290.3	181	2.00	580.61	1.60	$3.20
Tomatoes - Slicers	1,315.4	454	2.50	3,288.60	2.90	$7.25
Tomatoes - Grape	342.9	127	4.00	$1,371.69	2.70	$10.80
Total Receipts		**1,814**		**$9,644.44**		**$5.32**

Annual Expenses	Total
Seeds/Transplants	135.00
Fertilizers	108.00
Miscellaneous Supplies	125.00
Water	86.40
Water Test	17.00
Irrigation Supplies	122.00
Total Annual Expenses	**$593.40**

March - September

Labor Costs	Hours	$/Unit	Total
Bed Preparation	17.00	12.00	$204.00
General Maintenance	23.00	12.00	$276.00
Planting	10.50	12.00	$126.00
Pest Management	0.00	12.00	$0.00
Harvest	48.80	12.00	$585.60
Total Hours	**99.30**		**$1,191.60**

Ownership Costs	Annual
Depreciation - Tunnel	$875.00
Depreciation - Plastic Cover	113.40
Total Ownership	**$988.40**

Total Costs	
Tunnel	$2,773.40
Per Square Foot	$1.28
Annual Returns Over Total Costs	
Tunnel	$6,871.04
Per Square Foot	$3.18

Iowa Vegetable Farm - Bell Pepper Budget Example

High Tunnel Size (sq. ft.) (30 x 72)	2,160 ft.
Utilization	94%
Approximate Original High Tunnel Cost	$7,000.00

Receipts	Yield	Sq. Ft.	$/lb	Total
Peppers - Bell (520 plants)	3,248.6	2030	1.30	4,223.23
Total Receipts				**$4,223.23**

Annual Expenses	Total
Seeds/Transplants	175.00
Fertilizers	108.00
Miscellaneous Supplies	125.00
Water	86.40
Water Test	17.00
Irrigation Supplies	122.00
Total Annual Expenses	**$633.40**

March - September

Labor Costs	Hours	$/Unit	Total
Bed Preparation	10.00	12.00	$120.00
General Maintenance	10.00	12.00	$120.00
Planting	9.00	12.00	$108.00
Pest Management	0.00	12.00	$0.00
Harvest	30.00	12.00	$360.00
Total Hours	**59.00**		**$708.00**

Ownership Costs	Annual
Depreciation - Tunnel	$875.00
Depreciation - Plastic Cover	113.40
Total Ownership	**$988.40**

Total Costs	
Tunnel	$2,329.80
Per Square Foot	$1.08
Annual Returns Over Total Costs	
Tunnel	$1,893.43
Per Square Foot	$0.88

Iowa Vegetable Farm - Cucumber Budget Example

High Tunnel Size (sq. ft.) (30 x 72)	2,160 ft.
Utilization	94%
Approximate Original High Tunnel Cost	$7,000.00

Receipts	Yield	Sq. Ft.	$/lb	Total
Cucumbers (390 plants)	2,538.0	2030	1.25	3,172.50
Total Receipts				**$3,172.50**

Annual Expenses	Total
Seeds/Transplants	70.00
Fertilizers	108.00
Miscellaneous Supplies	125.00
Water	86.40
Water Test	17.00
Irrigation Supplies	122.00
Total Annual Expenses	**$528.40**

March - September

Labor Costs	Hours	$/Unit	Total
Bed Preparation	10.00	12.00	$120.00
General Maintenance	15.00	12.00	$180.00
Planting	5.00	12.00	$60.00
Pest Management	0.00	12.00	$0.00
Harvest	40.00	12.00	$480.00
Total Hours	**70.00**		**$840.00**

Ownership Costs	Annual
Depreciation - Tunnel	$875.00
Depreciation - Plastic Cover	113.40
Total Ownership	**$988.40**

Total Costs	
Tunnel	$2,356.80
Per Square Foot	$1.09
Annual Returns Over Total Costs	
Tunnel	$815.70
Per Square Foot	$0.38

Iowa Vegetable Farm - Tomato Budget Example

High Tunnel Size (sq. ft.) (30 x 72)	2,160 ft.
Utilization	94%
Approximate Original High Tunnel Cost	$7,000.00

Receipts	Yield	Sq. Ft.	$/lb	Total
Tomatoes - Slicers (195 plants)	5888.2	2030	1.60	9,421.06
Total Receipts				**$9,421.06**

Annual Expenses	Total
Seeds/Transplants	80.00
Fertilizers	108.00
Miscellaneous Supplies	175.00
Water	86.40
Water Test	17.00
Irrigation Supplies	122.00
Total Annual Expenses	**$588.40**

March - September

Labor Costs	Hours	$/Unit	Total
Bed Preparation	10.00	12.00	$120.00
General Maintenance	25.00	12.00	$300.00
Planting	5.00	12.00	$60.00
Pest Management	0.00	12.00	$0.00
Harvest	49.00	12.00	$588.00
Total Hours	**89.00**		**$1,068.00**

Ownership Costs	Annual
Depreciation - Tunnel	$875.00
Depreciation - Plastic Cover	113.40
Total Ownership	**$988.40**

Total Costs	
Tunnel	$2,644.80
Per Square Foot	$1.22
Annual Returns Over Total Costs	
Tunnel	$6,776.26
Per Square Foot	$3.14

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University of Kentucky
College of Agriculture, Food and Environment
Cooperative Extension Service

Center for Crop Diversification Fact Sheet
CCD-FS-2

What to Think About Before You Plant

Marketing Considerations for Kentucky Specialty Crop Growers

Tim Woods, Extension Professor, Agricultural Economics
Matt Ernst, Independent Writer, Center for Crop Diversificatio

Introduction

Commercial fruit and vegetable production in Kentucky increased from $15 million in farm sales in 1997 to more than $30 million in 2011. Transition from tobacco production spurred the growth of Kentucky's commercial produce industry in the early 2000s. Crop diversificatio continued to drive expansion in Kentucky's produce industry by 5 to 10 percent annually, with 2016 sales of fruits and vegetables totaling almost $37 million.

Specialty crops generate interest from both established and newer Kentucky farmers. These include, but are not limited to, those seeking to generate retirement incomes from their land, those investigating income possibilities from certified organic production, and those focusing on growth in the market for local foods and from urban farming enterprises.

This publication poses questions that can benefit farmers who are considering planting a new crop. Long-time commercial farmers and diversifying tobacco producers, as well as those newer to farming will find the questions, considerations, and checklists contain helpful tools for considering a new produce enterprise.

The publication is divided into the following six sections, with the majority of the content focused in the first two

- Market options by size and scale of production
- Conducting basic market research
- Certification
- Insurance and risk management
- Management and labor needs
- Resources needed beyond the field or garde

CENTER FOR CROP DIVERSIFICATION

Market Options by Size and Scale of Production

Kentucky's commercial produce growers range from those tending a small market garden for sale at their neighborhood farmers market to those employing mechanical harvesters to harvest dozens of acres of snap beans or sweet corn (See Page 11). Size and scale of production can help a producer determine where they will focus their marketing efforts.

Smaller produce growers typically focus on ***direct farm marketing***. Direct marketing is a general term describing marketing methods used to sell farm products directly to consumers. The most common forms of direct farm marketing in Kentucky are farmers markets, roadside stands, Pick Your Own/U-Pick, and Community Supported Agriculture. Generally, farmers markets are the easiest entry for new producers in terms of size and scale. U-Pick and CSA marketing tend to be the most intensive forms of marketing in terms of size and scale (Figure 1).

Farmers Markets are the most common outlet for direct marketing fruits and vegetables, with more than 150 markets located across Kentucky. A farmers market consists of multiple growers selling produce and other farm products at a single location. Many farms diversifying into produce have utilized a farmers market to start their direct farm marketing efforts, then focused on other direct market channels like on-farm markets and CSAs. Other producers have chosen to use a farmers market as their primary market channel throughout the entire life of the enterprise.

A **roadside stand** is a temporary, seasonal location

Figure 1. Marketing Options for Kentucky Produce Growers by Farm Size and Scale

Smallest Size/Scale
Farmers market
Roadside stand
Produce auction
Community Supported Agriculture (CSA)
Local wholesale (restaurant, grocery, institution)
U-Pick
On-farm stand
Regional wholesalers, brokers
Chain store distribution centers
Processors
Largest size/scale

where producers sell produce directly to the public. Roadside stands may not require much capital investment; they may be as simple as selling sweet corn out of the bed of a pickup truck. **On-farm stands** are permanent structures at or near the farm that serve as a retail location. Considerable investment and capital may be required for on-farm stands.

Produce auctions are an entry-level form of wholesaling in Kentucky.

Community Supported Agriculture (CSA) is a form of direct marketing where individual growers or a group of growers solicit subscribers within a community who pay a fixed monthly or seasonal fee to have a specified mix of fresh produce delivered to them on a weekly basis. CSAs may involve less than half a dozen subscriptions to hundreds of subscribers. The need for crop planning and delivery can result in CSAs requiring more intensive marketing efforts than other direct market channels. See University of Kentucky CSA resources here.

Pick Your Own (PYO), or **U-Pick** marketing, involves inviting the public onto the farm to harvest their own crops. Tree fruit, berries, and pumpkins are popular PYO crops. While PYO marketing can reduce the need for additional harvest labor, it also requires adequate supervision and staffing to oversee the public coming onto the farm.

Although not technically direct farm marketing, where the crop is sold directly to the final consumer, selling **direct to local restaurants or grocery stores** shares many of the same characteristics with direct-to-consumer outlets. One key difference is that such small-scale, wholesale markets require greater quantities and uniform product quality. **Farm-to-school** marketing would be included in this category.

Produce Auctions are an entry-level form of wholesaling for produce growers in Kentucky. There were five produce auctions selling in Kentucky during 2015. Produce auctions reward product quality and consistency but may also present the challenge of variable producer prices tied to attracting consistent buyers. Some growers choose to market their surpluses at produce auctions.

Wholesale production will typically involve much larger production systems and usually more mechanization from planting to harvest. **Regional wholesalers** and **food brokers** supply produce to institutions and grocery stores. They demand uniform quality, larger quantities, and offer prices that track with wholesale market trends. There have been some efforts among Kentucky growers in the past to supply such customers through forming marketing cooperatives that consolidate produce from numerous producers before packing and shipping through wholesalers and brokers.

With the increase in consumer demand for locally grown foods, grocery chains have upped their purchases of regional and local produce. Chain store distribution centers often accept produce directly from growers. Some grocery chains continue increasing *direct store deliveries*, where farms ship produce direct to the store where it will be sold.

Growing vegetables and fruit for wholesale to **processing** outlets has decreased in importance in Kentucky and surrounding states as canneries became more geographically focused in other regions. Growing for processing is now more typical to supply smaller-scale processors, such as apple cider and wine, that may be marketed at higher price points.

Producer Checklist for Size and Scale

After selecting a number for each statement below, add up the values of your answers. Low scores (<20) could indicate greater suitability for larger-scale, wholesale enterprises; higher scores (30-40) generally indicate suitability for smaller-scale, direct marketing enterprises.

	No, Not so much				Yes, Very much so
I want to have a personal connection with the consumers who will be eating the food I am growing	0	1	2	3	4
I am willing to spend a large amount of time in marketing my crop: connecting with customers personally or via farm communications.	0	1	2	3	4
I derive a large part of my income from employment off the farm.	0	1	2	3	4
My farm does **not** have any livestock, tobacco or row crop (corn, soybean, etc.) production	0	1	2	3	4
I do not have access to packing and/or cool storage facilities	0	1	2	3	4
I have much excess time to devote to developing a produce or new crop enterprise	0	1	2	3	4
I lack access to financial capital for establishing a new enterprise	0	1	2	3	4
I have little experience selling products that can fluctuate in prices	0	1	2	3	4
I would prefer to focus on producing small quantities of high-quality food crops	0	1	2	3	4
I want to establish close personal relationships with my end consumers/users	0	1	2	3	4
Total					

Conducting Basic Market Research

Whether you are interested in selling a few vegetables at your local farmers market or are establishing many acres of fruit for wholesale production, you will need to conduct some basic market research. Market research helps a producer establish who their customers will be and how much those customers are likely to be willing to pay for your products.

Several questions are basic to the market research process, no matter what size or scale the farm enterprise and marketing efforts:

- Who will my customer be, and what are the preferences and characteristics of that customer?
- What product will I be producing?
- What market channel will I be selling through?
- What price can I expect to obtain?

Who will my customer be, and what are the preferences and characteristics of that customer?

Successful marketers of all sizes and scales start by identifying their potential customers. Questions about potential customers include:

Good marketing plans start with the customer and work backward to production. Potential growers should first determine exactly what buyers want, how they want it, and when they want it. Then, they should determine how these crops should be grown. Even selecting varieties and determining planting times are basic marketing decisions.
http://www2.ca.uky.edu/agcomm/pubs/id/id134/id134.pdf

✓ **What do my buyers want?**

Buyers may not simply want a "tomato." They may want a specific kind of tomato. Farmers market buyers may want a vine-ripened heirloom tomato; a wholesale buyer may want thousands of boxes of tomatoes ready

Community Supported Agriculture (CSA) customers pay a fee to receive a mix of fresh produce on a weekly basis.

to ship several hundred miles. Buyers wanting cherry tomatoes could greatly affect the amount of harvest labor required per row of farm production! Buyers may want tomatoes early or late in the season, affecting the production method and varieties selected. *Defining what the buyer wants will affect what a producer grows.*

✓ **How do they want it?**

The "how" of presenting produce crops is essential. For example, on-site research conducted at Kentucky farmers markets showed that these customers were hesitant to purchase farm-fresh blueberries packaged in the fresh blueberry industry's standard plastic clamshell containers. To these farmers market customers, blueberries in plastic clamshells did not "feel" like they were locally grown. Local supermarkets, on the other hand, greatly preferred local blueberries packed according to the industry standard.

Wholesale buyers, like supermarkets and brokers, often have very specific guidelines for packing and delivering crops. These are often specified within production contracts. Because packaging can be a significant production expense for produce, it is essential for producers to determine how their customer wants the produce and factor it into their costs of production and marketing..

Farmers market and CSA producers have additional considerations for how produce is presented. Customers may prefer certain mixes of crops, and customers may even be interested in complementary products (such as preserves, eggs, and flowers) that may be marketed through such channels. Surveying customers — as simple as chatting with customers of a farmers market stand about how they perceive your product or what new products they would like to purchase — can be an important part of defining the *how* of your produce crop.

✓ **When do they want it?**

Timing and **delivery** are aspects of producing fruit and vegetable crops that are very important to buyers. A chef counting on a certain quantity of farm-fresh produce for that evening's menu does not want to discover the producer is unable to deliver that afternoon. Failure to deliver according to the stipulations of a production or marketing contract could void a contract or affect the commitment of a commercial buyer to follow through with subsequent purchases.

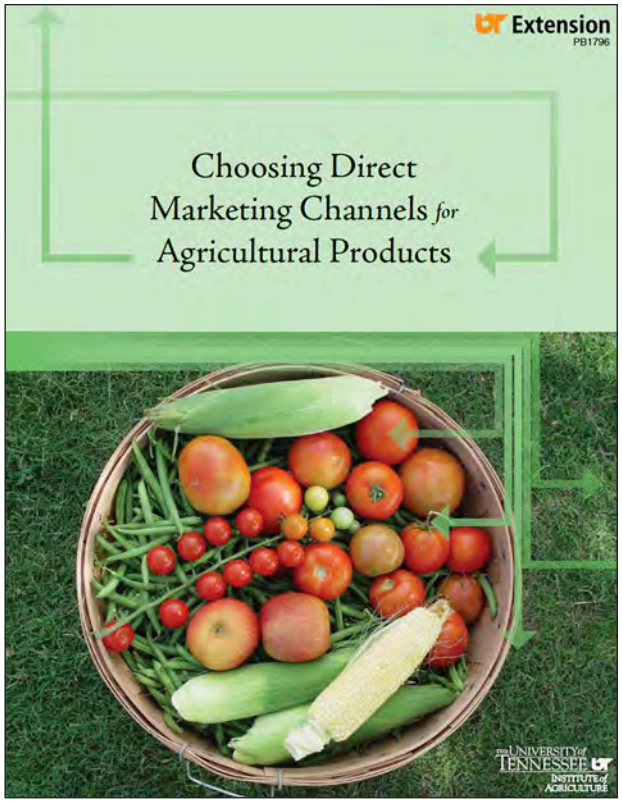
Many buyers indicate that a grower's failure to deliver product when it is needed or has been promised is a frequent mistake for beginning produce growers. In addition, producers marketing directly to the consumer (at farmers markets, stands, and through CSAs) will need to deliver their products when the customer is

present or expecting delivery.

Growers should understand when their customer expects delivery, meet that expectation, and be committed to communicate clearly when delivery is delayed or may be impossible due to extraordinary circumstances.

What product will I be producing?

All fruits and vegetables are not created equal! **Product differentiation** refers to product characteristics and marketing efforts that distinguish one product from the other.



For example, a producer may decide that a farmers market stand is the best fit for his or her operation. In the process of deciding *how* to grow the crops for sale, he or she may need to consider product attributes such as:

- Local variety preference
- Ease of picking
- Storage attributes of varieties
- Conventional, sustainable or certified o ganic production systems

What market channel will I be selling through?

For a good overview of many different market channels available to Kentucky growers, visit the Center for Crop Diversification website at www.uky.edu/CCD.

Another overview of direct market channels is available in a University of Tennessee Extension publication, *Choosing Direct Marketing Channels for Agricultural Products* (left). This publication is available for download at http://cpa.utk.edu.

What price can I expect to obtain?

It is very important that you have an idea of the price you can expect to obtain for your crops before making the decision to grow a certain crop. Many produce crops will require a certain price level to justify the investments needed for production.

Wholesale produce prices are reported by the USDA Agricultural Marketing Service at its fruit and vegetable market news portal, https://www.ams.usda.gov/market-news/fruits-vegetables. This source reports prices at *terminal markets*, which are wholesale market points across the country. Prices are also reported from *shipping points*, places near production centers from which fruits and vegetables are shipped. You can explore AMS retail reports here.

A listing of prices from Kentucky's produce auctions is maintained at www.uky.edu/ccd/pricereports/KYPA. These prices are updated with new auctions and can provide a useful reference point for producers within the vicinity of an auction who are considering using the auction market.

A report of farmers market prices in and near Kentucky is located at www.uky.edu/ccd/pricereports. This report focuses on markets from particular regions and can provide information about crop and product offerings across the state as well as price points.

Market channels used by Kentucky producers to sell fruits and vegetables include:

Farmers Markets	Restaurants	Schools and Institutions
Wholesale	Grower Cooperatives (Co-ops)	Pick Your Own
Roadside Stands	On-farm Stands/Roadside Markets	Produce Auctions
Community Supported Agriculture (CSAs)	Internet	Produce Brokers

Table 1. Selected Characteristics of Produce Packaging and Mix by Market Channel, KY

	Product Mix	Packaging	Grading and Quality Assurance
Farmers market	Important	"Farm" feel	May be flexible
Roadside stand	Important	Convenience	May be flexible
Produce auction	Single products	Auction standards	High grade/quality rewarded by price
Community Supported Agriculture (CSA)	Products in shares/baskets complement each other	Convenience, attractiveness of presentation	May be flexible—some may prefer 3rd party audit
Local wholesale (restaurant, grocery, institution)	Chef or buyer specifications	May be defined by industry standard and/or convenience	Uniform quality essential
U-Pick	Determined by ease of harvest, local and farm preferences	Bulk containers or customers may provide some packaging	Customers select preferred products; producer directs to ripe crops
On-farm stand	What customers want	Convenience; packages may help build farm brand	Price breaks may be given for lower grades
Regional wholesalers, brokers	Specified by buyer	Commercial produce standards	Uniform quality is essential
Chain store distribution centers	Specified by buyer and/or contract	Chain standards	Uniform quality is essential — consider 3rd party audit
Processors	Specified by buyer and/or contract	Bulk packaging for shipment common	May involve less stringent grading

Selected Characteristics of Produce Packaging and Product Mix by Market Channel

The table above summarizes produce packaging and product mix by market channel. Several terms used in the table are useful for understanding how markets for new crops are developed.

Product Mix refers to the different types of products sold at or through a specific market channel. For example, many farmers market vendors in Kentucky sell higher volumes of crops that are traditionally popular with customers, such as tomatoes and green beans. Lower volumes of new or minor crops, such as kohlrabi or specialty squash or peppers may be helpful at a farmers market stand. Some wholesale buyers may ask a producer to supply more than one crop — both watermelons and cantaloupes, for example — in order to buy from them. For some markets, it makes sense to focus on fewer products to reduce costs of production, develop growing expertise, and realize labor savings (per acre) that could result from higher volumes of production.

Packaging is one of the most overlooked costs for new produce growers. Developing attractive packaging is critical for those selling produce through retail chan-

nels. In wholesale channels, packaging is more functional, with designs to move produce safely and efficiently. Packaging, like bags, cartons and boxes, tends to be much less expensive per unit when purchased in bulk. Reusable plastic containers (RPCs) are used by some grocers and wholesalers for shipment from the farm to the merchandiser. While higher in upfront costs ($10-$20 per unit compared to $1-$3 for a corrugated box), RPCs are reusable and may save money in the long run. However, just like before growing a new crop, producers should always determine their customers' packaging preferences before investing in a particular packaging unit or style.

Proper labeling and identification for purposes of traceability (being able to identify what farm and/or field a crop originated in) has increased in importance for produce marketing. A clear and attractive farm label may also help consumers recognize a particular farm's products, adding value for the producer. Other information included on labels that may help a product's consumer acceptance includes listing certifications such as Kentucky Proud, Certified Organic, sustainably or naturally grown, and other product attributes.

The Packer is a well-known commercial produce industry publication that annually publishes a resource called *The Packer Produce Merchandising & Availability Guide*. This resource provides industry standards for packaging and compares differences between the ways produce may be packaged for grocery buyers compared to foodservice buyers. Standard produce packaging types are also listed in the *Wholesale Packing Resource Guide* from the New Entry Sustainable Farming Project. It is available through the SARE website at www.sare.org.

The previous two sections have described market options by size and scale of production, discussed conducting very basic market research, and examined considerations specific to different market channels. The following sections contain vitally important considerations for what to think about before planting produce: certifications, insurance, resources required beyond the field, and management and labor needs

Certification

Certifications allow produce growers to market their products under a particular labeling or program name. Common certifications in produce marketing in Kentucky include:

Kentucky Proud – produce sold by a farm enrolled in the Kentucky Department of Agriculture's Kentucky Proud program. For more information, refer to www.kyagr.com.

Kentucky Farm Bureau Certified Roadside Farm Markets – a program administered by the Kentucky Farm Bureau Federation. For more information, visit www.kyfb.com.

USDA Certified Organic – produce grown under inspection and certification in the USDA National Organic Program, administrated within the Agricultural Marketing Service. For more information, refer to www.ams.usda.gov.

Eco-labels – allow producers to market products to consumers while providing special environmental information about the product. Certified Organic products are one example of an eco-label. Other eco-labels gaining popularity with some produce growers include various forms of "certified sustainable" or "naturally grown" programs. Most of these programs require certifications and/or inspections for products to carry a particular label.

There are also other kinds of certifications that may apply to Kentucky produce. The following two guidelines address ways producers could avoid some of the more common pitfalls made by farm marketers with respect to certifications

- Maintain extensive files documenting and supporting any claims made and participation in programs allowing those claims. This is a must for anyone advertising, using signage, or making media claims of

particular certifications (Kentucky Proud, Certified Organic, etc.)

● Avoid making improper health claims relating to proven or perceived benefits of certain products. Health claims in food products are closely monitored, and producers of some farm products — particularly value-added products — can be required to redesign packages and labels or even remove product from the market if making claims that go beyond approved guidelines for food products. The Food and Drug Administration (FDA) is the regulating agency monitoring this issue.

There may also be local certifications that are necessary or optional for different marketing activities. To avoid making unsubstantiated claims, producers should contact and work with the appropriate local and regional agencies or organizations involved in administrating such programs.

Insurance and Risk Management

Businesses take on risks of various kinds, and agricultural businesses face unique kinds of risk associated with production that is dependent on biological processes. Two types of risk include *production* risks and *liability* risks.

Production risks occur from the uncertainties of agricultural production. Weather, insects and disease are the more common production risks incurred in fruit and vegetable production. Produce growers may spread risk out across different planting times. For example, planning an early planting to capture higher prices may incur a risk of frost, but that risk could be managed by using row covers or other covered production. Similarly, different varieties of the same species could be planted, with some varieties resistant to common diseases in a particular region. This practice could help manage the risk of crop failure due to disease. Careful planning and constantly learning about improving production methods can help producers manage such risks.

Low tunnels provide protection against frost.

Liability risks generally refer to the danger of being sued or becoming otherwise financially liable for accidents or faulty products. Another common but faulty assumption made by new fruit and vegetable crop producers is that their existing farm liability insurance policy will cover their new enterprise. Such a determination may be properly made only upon consulting with an attorney or insurance professional.

Two kinds of liability related to growing produce crops are *general* liability and *product* liability. Producers using on-farm marketing (like Pick Your Own or a roadside stand) expand their operation's risk in the area of general liability. Insurance providers may recommend adding coverage to policies or even acquiring a new policy specific to a new business enterprise.

Product liability insurance is coverage against liabilities resulting from faulty products sold by a grower. Many wholesale, institutional, and restaurant buyers have certain requirements for product liability insurance coverage for produce growers. Product liability insurance (PLI) is especially important in today's food safety and regulatory environment. Most producers find the cost of PLI relatively modest for the level of security provided and access to markets that PLI may enable.

Growers need to be aware of the Food Safety Modernization Act (FSMA) and how it affects their operations. For information about FSMA, Kentucky's Produce Best Practices Training, and Third-Party GAP, which is required by some buyers, visit the CCD's Produce Food Safety page at http://www.uky.edu/ccd/foodsafety.

There are many types of risk incurred in producing and selling fresh produce. But sound planning and proper use of risk management tools can minimize the risks faced by many growers.

Management and Labor Needs

Different crops will require different levels of management as well as varying labor requirements. Managing part-time harvest labor, conducting economic and market analysis, and preparing detailed marketing and business plans are routinely conducted by successful produce growers large and small.

Before planting a new crop, review information detailing production and labor requirements. The University of Kentucky College of Agriculture, Food and Environment maintains a library of new crop profiles at the website of the Center for Crop Diversification, www.uky.edu/ccd. Each profile includes a section listing the labor needs for production and harvest of a crop.

Also consider improving your management and marketing skills. Several specialized courses, available at reasonable costs, can help walk farm producers through new enterprises. Some resources may be available through organizations like the Small Business Development Center or the Kentucky Center for Agricultural and Rural Development, while others may be offered through the Cooperative Extension service. Contact your local county Extension office for details

Summary: Resources Needed Beyond the Field or Garden

The main idea conveyed in this publication is this: profitably producing a fruit or vegetable crop involves much more than "just" growing a crop successfully. Developing a clear plan for marketing the crop, as well as minimizing production and liability risks associated with that crop, are essential for increasing the likelihood of success. The earlier you can develop these plans and consider these variables before you plant, the better positioned you will be as a marketer.

The following resources contain many sources of information for developing and maintaining new produce enterprises. Producers are encouraged to seek out information from reliable sources and assemble their own library relating to their specific situations

University of Kentucky Center for Crop Diversification
www.uky.edu/CCD

Center for Profitable Agriculture
(University of Tennessee) http://cpa.utk.edu

Penn State Ag Alternatives
http://extension.psu.edu/ag-alternatives

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Reviewed by Brent Rowell, Extension Specialist, International and Sustainable Horticulture, University of Kentucky, and Brett Wolff, Extension Specialist, University of Kentucky Center for Crop Diversification. Photos courtesy of: Pexels.com (Pages 1 & 2); Fairview Produce Auction (Page 3); UK Agricultural Communications (Page 5); University of Tennessee Extension (Page 6); Kentucky Department of Agriculture, Kentucky Farm Bureau, USDA (logos, Page 8); Tim Coolong (Page 9)

2018

Marketing Channel Options for Kentucky Produce

(Adapted from ID-134, Marketing Options for Commercial Vegetable Growers, Brent Rowell, Tim Woods, Jim Mansfield, 1999)

Considerations	Direct: Roadside stand, Farmers Market, CSA	Direct: U-Pick, on-farm	Produce Auctions	Local Wholesalers, Grocers, Restaurants	Regional Wholesalers, Chain Store Distribution Centers, Brokers	Processors or Fresh-Cut
Production and Marketing Challenges						
Difficulty getting into the market	Low	Low-medium	Low	Medium	High	Medium-high
Marketing time required	High	Medium-high	Low	Medium-high	Medium	Low
Compatible with off-farm employment	Yes	Yes	Somewhat	Somewhat	Difficult	Yes
Compatible with row crop, tobacco, livestock production	Yes	Yes	Yes	Somewhat	Difficult during planting, harvest	Yes
Importance of product quality and shelf life	Medium-high	Medium	High	High	High	Medium
Investments: Time and Money						
Initial commitment level required	Low-high	Low	Medium	High	High	Low-medium
Management level required	Low-high	Medium	Medium	High	High	Low
Initial capital investments required	Low	Low-medium	Medium	Medium-high	High	Variable
Postharvest equipment and facilities investment required	Low	Low	Low	Medium	High	Variable
Income and Potential						
Prices	High	Medium-high	Medium-low	Medium-high	Medium	Low
Price stability	High	High	Medium-low	Medium-high	Medium	High
Product volume required	Low	Low	Medium	Medium	High	Medium
Market/sales volume potential	Low-medium	Low-medium	High-medium	Medium	High	Low
Likely further development potential in Kentucky	Excellent	Good-Excellent	Good	Good-Excellent	Fair-good	Low-fair

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University of Kentucky
College of Agriculture, Food and Environment
Cooperative Extension Service

Center for Crop Diversification Crop Profile
CCD-CP-60

High Tunnel Leafy Greens & Herbs

Cheryl Kaiser[1] and Matt Ernst[2]

Introduction

High tunnels, also known as hoop houses, are simple polyethylene-covered unheated structures. They can be covered with one or two sheets of plastic; those covered with two have an air layer in between, thus offering better insulation and, consequently, more cold protection.

While they are often used to extend the growing season earlier into spring and later into fall, high tunnels can be used in the mid-Atlantic region for winter production of a wide variety of leafy greens and herbs. "Leafy greens" is a broad term that includes vegetables such as lettuce, spinach, and leafy plants in the Brassicaceae family. In addition to winter production, shaded and well-vented high tunnels can be used to grow some of these cool-season crops into early summer, when it would otherwise be too hot for production.

Marketing

High tunnels and other season extension techniques allow producers to extend the time period over which cash flows are generated from produce crops. High tunnel production is expanding to supply the increasing demand for locally grown produce, as well as policy and grant programs favoring high tunnel production. High tunnel production of leafy greens and herbs can also enable producers to market products at higher prices, before the start of a traditional local season. High tunnel leafy greens and herbs are typically added by producers already selling through direct markets: farmers markets, CSAs (community supported agriculture programs), and direct to local restaurants and groceries. Farmers market producers entering winter might

generate a subscription list and establish a pickup location or delivery service for leafy greens and herbs grown in high tunnels. Social media and/or email distribution lists are great ways to notify customers of product availability and the order deadline for the week. Orders can then be received via return email or by phone.

Greens produced by extending the season into early summer can be sold retail via roadside stands and farmers markets. Bagged leaf lettuce mixes (sometimes called "mesclun mix") are popular at these markets. Wholesale marketing avenues include restaurants and locally owned grocers. Other local and regional marketing opportunities may be available for bagged salad and greens mixes, especially if they are certified organically grown. If offering bagged greens, herbs, or salad mixes, producers should always confirm they are meeting Best Handling Practices and food safety regulations applying to their product.

CENTER FOR CROP DIVERSIFICATION
www.uky.edu/CCD

[1]Cheryl Kaiser is a former Extension Associate with the Center for Crop Diversification.
[2]Matt Ernst is an independent contractor with the Center for Crop Diversification.

Market Outlook

Consumer use of fresh leafy greens and herbs increased during the early 2000s as consumers demanded a more diverse selection of leafy greens and decreased their average consumption of head lettuces, especially iceberg. The shift toward leaf lettuces continued from 2010 to 2015. High tunnel production of greens and herbs often targets a specific type of customer, one willing to pay for certain products or product quality during the off-season. Since this demand can vary between local areas, producers should identify what other high tunnel production is nearby. High tunnel production may command a price premium if high quality and steady supply are maintained to meet local demand. A good marketing plan can help the producer identify nuances in the local market and adjust planning and production accordingly.

Some growers have found winter greens to be the most profitable use of high tunnels on the farm. Additionally, growers may benefit financially from producing cool-season greens in shaded tunnels during late spring and early summer, when Kentucky field production is winding down but consumer demand persists. Providing fresh off-season greens retains existing customers and helps attract new customers.

Production considerations

Growing environment

High tunnels can provide the protective environment necessary for growing greens throughout the winter months. Tunnels are passively solar-heated, and nighttime low temperatures within a high tunnel can be a few degrees warmer than outside temperatures. Row covers used in conjunction with the high tunnel will provide additional cold and frost protection. Because row covers also block sunlight, they should not be left on for prolonged periods during the winter. Placing the row covers over hoops will help to keep tender leaves from freezing to the fabric. As an alternative, a heater can be used when unexpected drops in temperature occur. However, due to rising energy costs, the use of heaters should generally be limited to short durations. Often these extra precautions against cold are not necessary, as many greens will recover from an overnight freeze and continue to grow with warming temperatures the following day. A grower who has received NRCS EQIP funds to purchase a high tunnel should check his/her state's NRCS High Tunnel System Conservation Practice Standard to make sure heaters are allowed. NRCS allows the permanent installation of heaters in Kentucky. Such additions should be included in the manufacturer's design and recommendations.

Opening the sidewalls is imperative for good air circulation and temperature control, even in winter. During sunny days, temperatures in the tunnels can be 30 to 40 ºF higher than outside temperatures, necessitating that the tunnels be adequately vented. Lacking the automated ventilation system of more elaborate greenhouses, high tunnels are ventilated by manually rolling up the sidewalls in the morning and closing them at night. Orienting the houses perpendicular to the prevailing wind on the farm will help facilitate air movement.

Because tunnels prevent natural rainfall from reaching plants, drip irrigation is essential. The irrigation system can also be used to provide fertilization during the season. Watering will need to be carefully managed during the winter. Very turgid plants may not recover as well from freezes, so it is best not to water immediately before temperatures drop below freezing. Plants should be irrigated only when tunnel temperatures are expected to remain above 32 ºF for a few days. Growers, therefore, will need to closely monitor both air temperature forecasts and soil moisture.

High tunnel production of leaf lettuce into early summer will require shade cloth. One experienced Kentucky grower uses 60% shade cloth, while 39% shade has been used successfully in Missouri and Kansas trials growing leaf lettuce and spinach. The combination of shade and irrigation keeps soils cooler, thus improving plant establishment and reducing bolting (flowering) problems. In spite of these successes, however, summer greens production in Kentucky is quite risky. Not only is the chance of bolting especially high, but greens often develop a bitter taste in very hot weather if they are not adequately watered.

Site selection

Although stand-alone greenhouses are normally oriented in a north-south direction in Kentucky, orienting a high tunnel in an east-west direction will maximize the amount of low winter sunlight reaching plants. Select a level, well-drained, fertile location for greens production. Site selection is more critical when

the high tunnel is built to be a permanent structure. Once permanent tunnels are in place, amending the soil each year could present a challenge. A small tractor with a tiller can be driven into tunnels with hinged endwalls. However, if the endwalls are fixed, soil preparation will need to be accomplished by hand or with a small power tiller.

Moveable high tunnels can be relocated to a new site each season to facilitate crop rotation and to avoid nutrient depletion of the soil. Another benefit to moveable tunnels is the ability to rotate the high tunnel to different locations in the field to prevent the buildup of soil-borne diseases. Often tunnels that remain in the same location, producing the same crop for a number of years, will have high levels of soil pathogens. This leads to progressively high disease loads and crop losses. The soil in moveable tunnels should be worked prior to erecting the structure.

Plant selection

Greens producers will need to diversify their crop offerings with an assortment of colors, textures, and leaf shapes to appeal to consumers. Select crops that are both marketable and winter hardy. Winter greens that have a history of success in Kentucky high tunnels include: arugula, Chinese cabbage, endive, Mizuna (Japanese mustard), mustard greens, Pak Choi, Russian kale, spinach, and Tat Soi (Asian mustard). Lettuces include Bibb (Boston), leaf, and romaine (cos). The following herbs could potentially be grown in high tunnels: cilantro, chives, dill, garlic chives (Chinese leeks), oregano, parsley, sweet marjoram, and thyme. For early summer production, select crops and cultivars that are bolt-resistant. Growers will need to experiment with crops and cultivars to determine what works for their production system at their particular location.

Planting

Winter greens are either direct-seeded or transplanted into ground beds. In general, plants that are harvested as heads are transplanted, while those harvested as individual leaves are seeded. Transplants should be 4 to 6 weeks old, depending on the crop. Greens can be re-seeded or transplanted every three to six weeks for a continuous harvest. Early fall plantings of spinach may require pre-germinating seed for one week in a cold room or refrigerator. Once soils cool, pre-germination is no longer necessary.

Raised beds, which enhance soil warming in the spring, may actually be a detriment to winter crop production; soils in raised beds do not stay as warm as soil-level beds.

Leaf lettuces for early summer production require extra attention. Plants will grow quickly and need to be harvested in a timely manner. Because plant regrowth usually suffers from a loss in quality, a planting may only yield a single cutting. After harvest, plants are turned under and the area seeded for the next crop.

Pest management

Due to the unique environment within tunnels, growers may encounter different disease problems within the tunnel than in the field. Because the tunnel excludes rainfall, the foliage tends to stay dry, resulting in fewer disease problems due to those pathogens that are spread by rain splash or require leaf-wetness for infection. However, due to the limited movement of air in a tunnel, diseases favored by high humidity could increase in severity. These include gray mold, leaf mold and powdery mildew.

Insect pests in tunnels differ as well. While the high tunnel presents a barrier to some insects, it is an ideal environment for others, particularly whiteflies and aphids. Typically any insect that is a problem in a greenhouse environment will be a problem in a high tunnel. Additionally, grasshopper feeding can occur throughout the winter since the ground within the tunnel does not freeze. Without natural predators, such as birds, to help keep insects in check, serious infestations may develop very quickly.

Due to the relatively high density of plants in tunnels, pests and diseases tend to spread rapidly. Frequent scouting to monitor insect populations and disease is essential to keeping these problems manageable.

Harvest

Leafy greens are hand-harvested as whole plants (once over harvest) or as individual leaves (multiple harvests). Because the harvested products are leaves (which rapidly lose water), care must be taken to cool, pack, and sell them promptly.

Romaine, Boston lettuce, Chinese cabbage, and Tat Soi are harvested as whole pants. They are cut at the

base with a knife once heads have reached the desired size and density.

Crops sold in bunches include herbs, arugula, and other greens. The leaves are cut with a knife or scissors, leaving sufficient plant material for regrowth (about an inch above the soil surface to protect the growing point). Many growers harvest a set number of leaves per plant to maximize the number of harvest weeks. Endive must be harvested before a strong bitter taste and toughness develops that makes it unmarketable. Leaves are bound with rubber bands or produce ties. Some plants wilt quickly and may need to be stored in water until packed or delivered.

Greens to be sold in bags as a mesclun mix or braising mix are either hand-picked or cut with sharp scissors to minimize cell damage and prolong quality, and then placed in bins.

Labor requirements

High tunnel greens production for 20 weeks from a single 96-foot by 20-foot house requires labor for site preparation (10 to 15 hours), planting (three to six hours), production (10 hours), and harvest/packing/marketing (40 to 100 hours). Harvest times are highly variable depending on crop mix and selection. Crops that include greens, Bibb (Boston), and romaine lettuce can be harvested and packed in considerably less time (40 to 60 hours) for the season than herbs and leaf lettuces (50 to 100 hours). In addition, high tunnels will require daily labor to manually raise and lower sidewalls (15 to 20 hours). These structures could also require monitoring during heavy storms. Additional labor may be required for producers marketing their own greens.

Economic considerations

Initial investments include high tunnel construction, land preparation, purchase of seed or transplants, and installation of an irrigation system. Additional start-up costs could include black plastic mulch, row covers, and an inflation fan. Seed costs for specialty greens and herbs may be higher than more common crops.

High tunnels are a relatively inexpensive way to extend the growing season. Excluding labor, the approximate materials cost of high tunnel construction is $1.30 to $1.50 per square foot. Site preparation and high tunnel systems, like ventilation fans and heating, can add about the same amount per square foot. High tunnel operators in Kentucky reported high tunnel construction costs during winter 2017 at $2.50 to $3 per square foot, plus the value of some operator labor. Compared to the cost of a traditional production-ready greenhouse ($8 to $30 per square foot), the high tunnel requires little capital investment. High tunnel production, however, does represent a much greater investment than growing produce in the field.

The following 2016 budget estimate is based on specialty lettuce production in a 96-foot by 20-foot high tunnel. Costs will be similar for other crops; higher value greens and herbs could result in potentially greater returns. Production costs for mixed greens are estimated at $440, with harvest and marketing costs at $500. Total annual expenses per tunnel are estimated at $1,440, which includes an annual fixed cost representing tunnel construction costs depreciated over 10 years.

Gross returns will vary widely according to local market conditions; presuming a conservative gross return estimate of $3,000, returns to land, capital, and management would be approximately $1,600. This estimate includes the cost of $10 per hour for all labor needs. Actual returns from high tunnel production of leafy greens may far exceed this estimate based on market demand and price.

A variety of greens and herbs can be grown in high tunnels in the winter months. Producers should formulate their own budget estimates based on what they know their potential markets are demanding. For example, members of a CSA might be surveyed as to whether they would prefer to receive early or late-season romaine lettuce, mesclun salad mix, herbs, or a combination of all three. While production costs for different varieties may be similar, good estimates before planting will allow the producer to accurately price their crop.

Selected Resources

- How to Build a High Tunnel (University of Kentucky) http://www.uky.edu/hort/sites/www.uky.edu.hort/files/documents/hightunnel.pd
- An IPM Scouting Guide for Common Problems of High Tunnel and Greenhouse Vegetable Crops in Kentucky (University of Kentucky, 2016) http://www2.ca.uky.edu/agcomm/pubs/ID/ID235/ID235.pdf

- Cornell High Tunnels - Greens (Cornell University) http://blogs.cornell.edu/hightunnels/vegetables/greens/
- High Tunnel Winter Cropping Systems (West Virginia University, SARE) http://www.sare.org/Learning-Center/SARE-Project-Products/Northeast-SARE-Project-Products/High-Tunnel-Winter-Cropping-Systems
- Organic & Sustainable Crop Production Grower Resources: High Tunnels (University of Tennessee) http://organics.utk.edu/growers.htm#HighTunnels
- Sample Budgets and Spreadsheets (Winter Greens) (Cornell University, 2009) http://blogs.cornell.edu/hightunnels/economics/sample-budgets-spreadsheets/
- Specialty Lettuce and Greens: Organic Production (ATTRA, 2002) https://attra.ncat.org/attra-pub/summaries/summary.php?pub=375

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Reviewed by Annette Wszelaki, University of Tennessee Vegetable Extension Specialist
Photo courtesy of Tim Coolong, University of Georgia Associate Vegetable Professor **July 2017**

For additional information, contact your local County Extension agent

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You will need Adobe Acrobat Reader to use these forms. If you do not have this program installed on your computer, you can download a free version **here**.

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Sample Pepper High Tunnel Budget using Plasticulture

Summary of estimated costs per 30 x 96 tunnel producing a single spring-planted crop using plasticulture and a conventional bio-approach option. Pennsylvania 2020.

Item	Quantity or number of operations	Your Quantity	Unit	Price	Your Price	Total	Your Estimate
Income							
Peppers - 1 1/9 bushel box	88		boxes	$27.25		$2,398.00	$ 0.00
Variable Costs							
Soil Test	1		kit	$13.00		$13.00	$ 0.00
Plant analysis kit	5		kit	$25.00		$125.00	$ 0.00
Fertilizer broadcast							
N	6.3		lb.	$0.23		$1.45	$ 0.00
P	5.3		lb.	$0.24		$1.27	$ 0.00
K	7		lb.	$0.24		$1.68	$ 0.00
Fertilizer Injected							
20-20-20	14.4		lb	$1.34		$19.30	$ 0.00
9-15-30	16.2		lb	$1.32		$21.38	$ 0.00
Magnesium	4		lb	$5.50		$22.00	$ 0.00
Potassuium	48		fl.oz.	$0.19		$9.12	$ 0.00
Calcium	48		fl.oz.	$0.15		$7.20	$ 0.00
Lime	80		lb.	$0.01		$0.80	$ 0.00
Pesticides							
Fungicides	1		crop	$186.29		$186.29	$ 0.00
Insecticides	1		crop	$94.59		$94.59	$ 0.00
Plastic mulch	480		ft.	$0.03		$14.40	$ 0.00
Drip tape	480		ft.	$0.03		$14.40	$ 0.00
Plants	600		each	$0.24		$144.00	$ 0.00
Tomato stakes	80		each	$0.40		$32.00	$ 0.00
Twine	20		100'	$0.20		$4.00	$ 0.00
Labor							
Operator labor	36		hour	$18.00		$648.00	$ 0.00
Hand labor	43.2		hour	$15.00		$648.00	$ 0.00

Harvest/Packaging/Marketing							
Harvest labor	88		box	$7.28		$640.64	$ 0.00
Tomato box	88		each	$1.75		$154.00	$ 0.00
Marketing	15%	0%	sales	$2,398.00	$ 0.00	$359.70	$ 0.00
Diesel Fuel	52.0		gallon	$2.60		$135.20	$ 0.00
Repairs & maintenance							
Tractors	1		crop	$46.80		$46.80	$ 0.00
Implements	1		crop	$50.46		$50.46	$ 0.00
Additional expenses							$ 0.00
Additional expenses							$ 0.00
Interest on operating capital	1		crop	$67.21		$67.21	$ 0.00
Total variable costs						***$3,461.89***	$ 0.00
Fixed Costs							
Tractor and equipment	1		crop	$135.61		$135.61	$ 0.00
Tunnel and plastic	0.5		year	$1,402.00		$701.00	$ 0.00
Additional expenses							$ 0.00
Land charge	1		crop	$15.00		$15.00	$ 0.00
Total fixed costs						***$851.61***	$ 0.00
Total costs						**$4,313.50**	$ 0.00
Returns							
Net returns over variable costs						**-$1,063.89**	$ 0.00
Net returns						**-$1,915.50**	$ 0.00
Break-even yield-boxes						**158**	
Break-even price-box						**$49.02**	

You should monitor local markets and contact suppliers to determine current prices for all items contained in this sample budget.

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Authors
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Sample Cucumber High Tunnel Budget Growing in Pots

Summary of estimated costs per 30 x 96 tunnel producing a single spring-planted crop growing in a pot system and a conventional bio-approach option. Pennsylvania 2020.

Item	Quantity or number of operations	Your Quantity	Unit	Price	Your Price	Total	Calculated Estimate
Income							
Cucumbers - 15 pound boxes	600		boxes	$18.00		$10,800.00	$ 0.00
Variable Costs							
Soil Test	1		kit	$13.00		$13.00	$ 0.00
Plant analysis kit	5		kit	$25.00		$125.00	$ 0.00
Fertilizer broadcast							
N	6.3		lb.	$0.23		$1.45	$ 0.00
P	5.3		lb.	$0.24		$1.27	$ 0.00
K	7		lb.	$0.24		$1.68	$ 0.00
Fertilizer Injected							
20-20-20	14.4		lb	$1.34		$19.30	$ 0.00
9-15-30	16.2		lb	$1.32		$21.38	$ 0.00
Magnesium	4		lb	$5.50		$22.00	$ 0.00
Potassuium	48		fl.oz.	$0.19		$9.12	$ 0.00
Calcium	48		fl.oz.	$0.15		$7.20	$ 0.00
Lime	80		lb.	$0.01		$0.80	$ 0.00
Pesticides							
Fungicides	1		crop	$186.29		$186.29	$ 0.00
Insecticides	1		crop	$94.59		$94.59	$ 0.00
Shade cloth[2]	2,880		sq.ft.	$0.05		$144.00	$ 0.00
Shade cloth stakes[2]	200		each	$0.20		$40.00	$ 0.00
Irrigation line[2]	340		ft.	$0.05		$17.00	$ 0.00
Irrigation spiders and fittings[2]	150		each	$1.50		$225.00	$ 0.00
Plants	600		each	$0.24		$144.00	$ 0.00
Twine	20		100'	$0.20		$4.00	$ 0.00
Tissue testing	3		tests	$25.00		$75.00	$ 0.00
Labor							
Operator labor	36		hour	$18.00		$648.00	$ 0.00
Hand labor	43.2		hour	$15.00		$648.00	$ 0.00

Packaging							
Harvest labor	9,000	0%	pound	$0.26	$ 0.00	$2,340.00	$ 0.00
Cucumber box	600		each	$1.15		$690.00	$ 0.00
Marketing	15%		sales	$2,398.00		$1,620.00	$ 0.00
Diesel Fuel	52.0		gallon	$2.60		$135.20	$ 0.00
Repairs & maintenance							
Tractors	1		crop	$46.80		$46.80	$ 0.00
Implements	1		crop	$50.46		$50.46	$ 0.00
Additional expenses							$ 0.00
Additional expenses							$ 0.00
Interest on operating capital	1		crop	$67.21		$67.21	$ 0.00
Total variable costs						***$7,397.75***	$ 0.00
Fixed Costs							
Tractor and equipment	1		crop	$135.61		$135.61	$ 0.00
Tunnel and plastic	0.5		year	$1,402.00		$701.00	$ 0.00
Additional expenses							$ 0.00
Land charge	1		crop	$15.00		$15.00	$ 0.00
Total fixed costs						***$851.61***	$ 0.00
Total costs						**$8,249.36**	$ 0.00
Returns							
Returns over variable costs						**$3,402.25**	
Net returns						**$2,550.64**	
Break-even yield-boxes						**458**	
Break-even price-box						**$13.75**	

1.Budget is for one crop of cucumbers. Many of the items may be used for more than one crop if grown consecutively.
2. Calculated at 35% of cost to allow for multiple uses.
You should monitor local markets and contact suppliers to determine current prices for all items contained in this sample budget.

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Sample Tomato High Tunnel Budget using Plasticulture

Summary of estimated costs per 30 x 96 tunnel producing a single spring-planted crop using plasticulture and a conventional bio-approach option. Pennsylvania 2020.

Item	Quantity or number of operations	Your Quantity	Unit	Price	Your Price	Total	Calculated Estimate
Income							
Tomatoes - 25 pound boxes	180		boxes	$38.00		$6,840.00	$ 0.00
Variable Costs							
Soil Test	1		kit	$13.00		$13.00	$ 0.00
Plant analysis kit	5		kit	$25.00		$125.00	$ 0.00
Fertilizer broadcast							
N	6.3		lb.	$0.23		$1.45	$ 0.00
P	5.3		lb.	$0.24		$1.27	$ 0.00
K	7		lb.	$0.24		$1.68	$ 0.00
Fertilizer Injected							
20-20-20	14.4		lb	$1.34		$19.30	$ 0.00
9-15-30	16.2		lb	$1.32		$21.38	$ 0.00
Magnesium	5		lb	$5.50		$27.50	$ 0.00
Potassuium	80		fl.oz.	$0.19		$15.20	$ 0.00
Calcium	80		fl.oz.	$0.15		$12.00	$ 0.00
Lime	80		lb.	$0.01		$0.80	$ 0.00
Pesticides							
Fungicides	1		crop	$216.33		$216.33	$ 0.00
Insecticides	1		crop	$114.35		$114.35	$ 0.00
Plastic mulch	480		ft.	$0.03		$14.40	$ 0.00
Drip tape	480		ft.	$0.03		$14.40	$ 0.00
Plants	300		each	$0.20		$60.00	$ 0.00
Tomato stakes	160		each	$0.40		$64.00	$ 0.00
Twine	60		100'	$0.20		$12.00	$ 0.00
Labor							
Operator labor	43.5		hour	$18.00		$783.00	$ 0.00
Hand labor	57		hour	$15.00		$855.00	$ 0.00

Harvest/Packaging/Marketing							
Harvest labor	180		boxes	$3.25		$585.00	$ 0.00
Tomato box	180		each	$1.50		$270.00	$ 0.00
Marketing	15%	0%	sales	$6,840.00	$ 0.00	$1,026.00	$ 0.00
Diesel Fuel	62.00		gallon	$2.60		$161.20	$ 0.00
Repairs & maintenance							
Tractors	1		crop	$55.80		$55.80	$ 0.00
Implements	1		crop	$57.71		$57.71	$ 0.00
Additional expenses							$ 0.00
Additional expenses							$ 0.00
Interest on operating capital	1		crop	$67.20		$67.20	$ 0.00
Total variable costs						***$4,594.97***	$ 0.00
Fixed Costs							
Tractor and equipment	1		crop	$154.56		$154.56	$ 0.00
Tunnel and plastic	0.5		year	$1,402.00		$701.00	$ 0.00
Land charge	1		crop	$15.00		$15.00	$ 0.00
Additional expenses							$ 0.00
Total fixed costs						***$870.56***	$ 0.00
Total costs						**$5,465.53**	$ 0.00
Returns							
Net returns over variable costs						**$2,245.03**	$ 0.00
Net returns						**$1,374.47**	$ 0.00
Break-even yield-boxes						**144**	
Break-even price-box						**$30.36**	

You should monitor local markets and contact suppliers to determine current prices for all items contained in this sample budget.

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Authors
Lynn F. Kime, senior extension associate; Steve M. Bogash, Marrone Bio Innovations, Thomas Ford, extension educator, and Krystal L. Snyder, extension educator.

December 2019 Horticulture/HighTunnel/2019-04

High Tunnel Site Selection

Tiffany Maughan, Dan Drost, and ***Brent Black***

High tunnels are an effective tool for extending the growing season and providing protection to high value crops. Although high tunnels are not considered permanent structures, most growers leave their tunnel in the same place for many years. Deliberate planning upfront to determine the best location on your property for a high tunnel is critical for success. This fact sheet details several factors you need to consider as you plan for a high tunnel.

Size

High Tunnels come in many shapes and sizes. Tunnel selection depends on space available, the crop being grown, equipment access needed, and expected wind and snow load issues. High tunnels can be constructed using commercial kits or built from scratch following design plans. Visit tunnel.usu.edu to see detailed construction plans for several different tunnels that have worked well in Utah.

Figure 1. High tunnels of different size and length.

Sunlight

Sunlight is one of the most important factors to consider when selecting a site for a high tunnel. Since high tunnels are an investment and the space inside is highly valuable, do not limit growth by limiting sunlight. Care should be taken to avoid placing the high tunnel where it will be shaded. Remember that during the fall and spring, when high tunnels provide the most benefit, the sun is at a low angle and casts longer shadows than during the summer. If there is a building south or west of the proposed site, set the high tunnel back 2 to 2.5 times the height of the building. When high tunnels will be next to each other, they can be built closer together (1 to 1.5 times the height of adjacent tunnels). When planting hear trees, remember tree height is not static. Since high tunnels remain in the same spot for several years, overtime, a small tree will become a large tree with significant shading potential.

Orientation

In general, orienting a high tunnel East/West maximizes sunlight exposure during the low-light period of winter and is best for late-fall, winter, and early-spring production. A North/South orientation has less crop shading (an important consideration for tall crops) and warms up more quickly in the morning, requiring earlier ventilation. For locations well above 40°N, East/West orientation is recommended. However, prevailing wind direction and topography should also be considered when deciding tunnel orientation and are covered in following sections.

Soil

High tunnels are used for very intensive production. It is critical that the soil in the high tunnel is healthy, free draining, and fertile. Avoid sites with compaction, soil-borne diseases, excessive weed pressure, water-logging issues, or locations where the same crop as you plan to grow has been growing for multiple years. Before building a high tunnel, have the soil tested and use this information to make soil improvements. USU's Analytical Laboratory tests soil and provides information on proper sample collection and test pricing.

Drainage/Topography

High tunnels displace rainfall. For example, a 30' x 96' structure sheds 1,728 gallons of water for every inch of rain. As the water runs down the sides of the tunnel, it needs to have a place to go that will not create issues for the high tunnel or surrounding crops, buildings, or roads. Consider creating a drainage ditch (figure 2) to direct water to where you would like it to flow. Avoid building a high tunnel in low spots or at the bottom of a hill to help prevent runoff flowing into or through the tunnel. Creating an elevated pad for the high tunnel to sit on helps ensure water drains away from the tunnel.

Wind

High tunnels can be significantly damaged by high winds. If possible, face tunnel end walls toward the prevailing wind to decrease the surface area the wind is hitting against and present the strongest side to the wind. If high winds are an issue in your area, windbreaks help protect a high tunnel. Keep in mind the shading potential of the windbreak when determining tunnel placement.

Figure 2. Lined drainage ditch to direct runoff.

Accessibility

High tunnels require daily monitoring and easy access is critical. If possible, build the high tunnel near the house or main farm buildings. Plan for year-round access. In areas that receive snow, special winter management is needed. Snow removal may require shoveling or plowing to keep levels low and avoid buildup around the tunnel (figure 3). It is important to have space to maneuver around all sides of the tunnel for these winter tasks. In addition, if power equipment (tractors, tillers, planters, etc.) are used in the tunnel, be sure there is sufficient room to maneuver these tools around the tunnel.

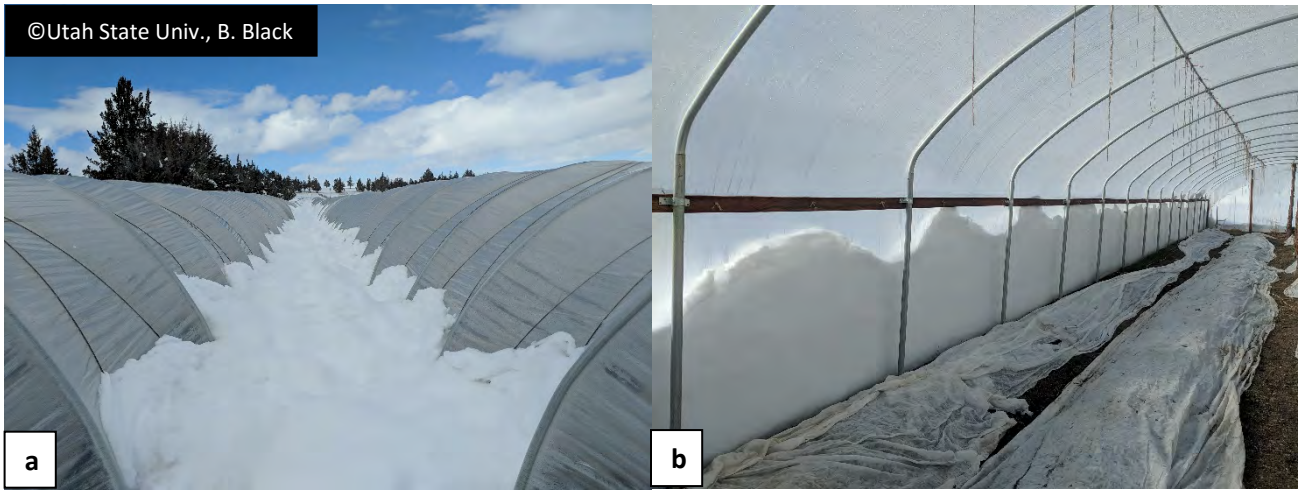

Figure 3. a) Snow build-up between high tunnels built too close together. b) Snow shading crops inside high tunnel.

Water

Select a high tunnel site where irrigation water is accessible. Secondary irrigation water can be used in a high tunnel but should be filtered before use with a drip system. High tunnel crops require irrigation during times of the year when secondary water may not be available. Building your tunnel next to a freeze-free, culinary water source will ensure year round irrigation is possible.

Figure 4. Freeze-free culinary water spout beside high tunnel.

Electricity

High tunnels are passively heated; however, there are situations where electricity may be needed at the tunnel. Consider running electricity out to your tunnel or build near a power source. Electricity may be needed during construction, if you plan on using automatic ventilation, electric heating (cables, heaters, light bulbs), or have other electricity needs. A solar panel connected to a deep-cycle battery with a voltage regulator (figure 5) is an alternative electricity option.

Building Code and City Ordinances

In 2015, Utah building codes were modified and now state that high tunnels are exempt from municipal regulation and do not require a building permit as long as they meet the following requirements:

- is not a permanent structure;
- is used for keeping, storing, sale or shelter of an agricultural commodity;
- has a metal, wood, or plastic frame;
- is covered with plastic, woven textile, or other flexible covering; and
- has a floor made of soil, crushed stone, matting, pavers, or a floating concrete slab.

Check with your city/county codes regarding edge of property and height regulations which may still apply.

Aesthetics

Finally, think of how the high tunnel will look on your property. Consider your (and your neighbor's) views.

Conclusion

It is likely that no one location will meet each of the site considerations discussed. As you select the best location for your high tunnel, decide which factors are most important for success and work to mitigate conflicting issues.

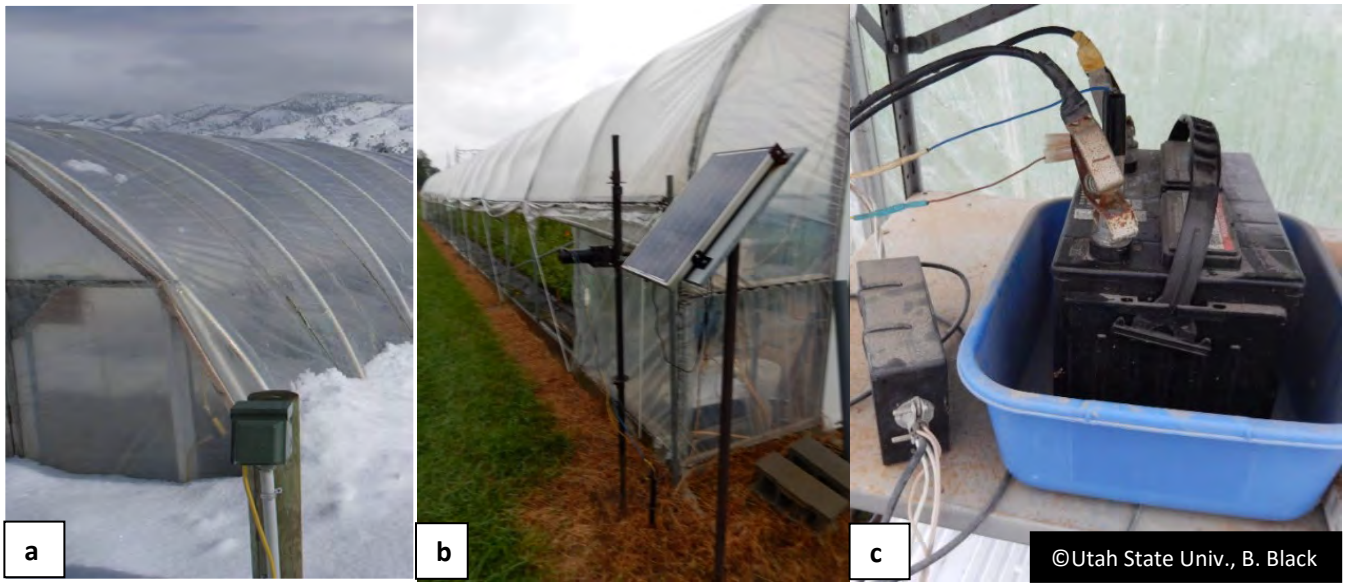

Figure 5. a) Power source near a high tunnel, b) solar panel connected to c) a battery with a voltage regulator.

Commercial High Tunnel Manufacturers

List is not all inclusive, listed alphabetically.

FarmTek
1440 Field of Dreams Way, Dyersville, IA 52040
https://www.farmtek.com/farm/supplies/homell

Haygrove
Redbank, Ledbury, Herefordshire, HR8 2JL, UK
https://www.haygrove.com/

Ledgewood Farm
132 Old Mountain RD, Moultonborough, NH 03254
http://www.ledgewoodfarm.com/

Poly-Tex
27725 Danville Ave, Northfield, MN 55057
https://www.poly-tex.com/high-tunnels/

Rimol
40 Londonderry Turnpike
Hooksett, NH 03106
https://www.rimolgreenhouses.com/greenhouse-series/high-tunnel

Tunnel Vision Hoops
3558 Lee Road
Shaker Heights, OK 44120
https://www.tunnelvisionhoops.com/greenhouses/

Additional Resources

Black, B., and D. Drost. 2010. Temperature Management in high tunnels. Utah State University Extension. Horticulture/HighTunnels/2010-04

Black, B., D. Drost, D. Rowley, and R. Heflebower. 2008. Constructing a low-cost high tunnel. Utah State University Extension. HG/HighTunnels/2008-01pr

Patterson, R. 2014. A high tunnel for strong winds and space utility. Utah State University Extension. Horticulture/HighTunnels/201-02pr

Maughan, T., D. Rowley, B. Black and D. Drost. 2014. Constructing a low-cost high tunnel for tall crops (14.5' wide by 10' tall). Utah State University Extension. Horticulture/HighTunnels/2014-05

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NRCS Natural Resources Conservation Service

High Tunnel System

Conservation Practice Job Sheet Code 325

DEFINITION

An enclosed polyethylene, polycarbonate, or plastic covered structure that is used to cover and protect crops to extend the growing season in an environmentally safe manner.

PURPOSE

To improve plant health and vigor

WHERE PRACTICE APPLIES

This practice applies to land capable of producing crops. This practice applies where an extension of the growing season is needed due to climatic conditions. The practice does not apply to crops not grown in the natural soil profile. Raised beds are limited to 12 inches in depth.

- Practice cannot be utilized to provide shelter or housing for any livestock.
- Practice cannot be utilized to store equipment or supplies.
- Practice does not include greenhouses or low tunnel systems.

Minimum Height: 6’ clearance in the center of the structure

Cover Material: Minimum of one layer 6 mil Greenhouse grade UV stabilized plastic rated for a 5 year lifespan.

LAYOUT AND LOCATION

- Choose a location with a moderately well-drained or well-drained soil.
- Locate the near a viable water source for irrigation.
- Locate the practice to avoid public utilities.
- Where feasible, locate the structure outside of the 100-year floodplain.
- Plan the high tunnel for convenient ingress/egress of plant materials, equipment, and other operation and maintenance activities.

SITE PREPARATION AND REQUIRED SUPPORTING PRACTICES

- Remove existing vegetation with herbicide, tillage, or a combination of both.
- Plan adequate drainage away from the structure to prevent erosion and ponding in and around the crop area.
- Level area with minimum soil disturbance.
- Check slope. High tunnel should not be installed on slopes greater than 5%.
- Plan supportive conservation practices to address all environmental concerns associated with the installation and use of the high tunnel systems such as erosion, irrigation, and runoff.
- Treat disturbed areas with Critical Area Planting (342) and Mulching (484) practices.

CONSIDERATIONS

- Consider structures with 4 foot spacing of bows because narrow spacing offers better stability than wider spaced bows.
- Set end posts in concrete, use of heavier 12 to14 gauge steel, and install a double layer of 6 mil plastic to increase integrity of the structure.
- Use concrete ground anchors to increase stability of permanent structures.
- Installation of bracing kits (when available) is highly recommended. Lateral and horizontal bracing can increase structural strength for snow and wind load.
- Install rollup sides for temperature regulation.
- For heat retention and increased strength, install a cover using two layers of 6 - mil, greenhouse-grade, UV resistant polyethylene. Use inflation fans to produce insulated air space. This system increases heat retention in the high tunnel and helps protect the cover from wind damage.
- Plan and install waterline for irrigation. Call 811 to determine and avoid buried utilities.
- Create a minimum clearance of 10 to 20 feet between side by side high tunnel installations for snow removal and cover installation.
- Prevent potential shading of high tunnel structures by other structures or trees and locate at a distance of two times the height of the tree or structure.
- Gothic style (peaked roof) high tunnels shed snow and ice more readily that rounded roof high tunnels.
- Capture and use roof runoff for irrigation purposes though runoff should not be relied on as the only source of irrigation water.
- Rotate the location of the tunnel or remove cover in winter to allow rain, wind, sun, and cold to cleanse soil from possible salt and disease buildup.

OPERATION AND MAINTENANCE

- Operation of equipment near or in the structure shall not compromise its intended purpose.
- To protect high tunnel framework from snow, ice, or wind damage, remove cover when not in use.
- To protect structure in high wind events, secure doors and all ventilation openings prior to inclement weather.
- Control weeds with soil fabrics, covers, or mulches.
- Maintenance and repair of the high tunnel structure is the sole responsibility of the individual. The covered area will be periodically be inspected and shall be replaced or repaired as needed to accomplish the intended purpose.
- If cost shared, the contract participant is expected to bear the costs of all repairs for the 5 year lifespan of this practice.

NRCS Natural Resources Conservation Service

KY Conservation Practice Job Sheet — Code 325

SPECIFICATIONS

Site-specific requirements and additional provisions are listed on the following pages. Specifications are prepared in accordance with the High Tunnel System (325) practice standard in the NRCS Field Office Technical Guide. This information is considered to be part of the contract and/or conservation plan.

Client:	**Farm #:**
Field(s):	**Tract #:**
Assisted By:	**Date:**
Contract #: (If applicable)	**Planned Growing Season:** _____ (month) **through** _____ (month)

STRUCTURE INFORMATION	
MANUFACTURER	**STRUCTURE SIZE**
Company:	**Width:**
Model:	**Length:**
Type:	**Total square foot** (L x W)
Add. Spec: (optional)	**Height:** (min 6' required)
If planting is required due to construction disturbance (complete as necessary) :	
Seeding dates: _____	**Lime:**_____(lbs./ac)
Fertilizer :_____(lbs./ac) or (lbs./sq. ft.)	**Mulch :**_____(lbs./ac) or (lbs./sq. ft.)

COMPONENT OR FACILITATING FOTG PRACTICES (Check all that apply. Refer to the individual specifications as applicable)	
☐ Diversion (362)	☐ Roof Runoff Structure (558)
☐ Irrigation System, Microirrigation (441)	☐ Critical Area Planting (342)
Other Conservation Practice:	
Species Planted:	Seeding Rate:

PRODUCER CERTIFICATION

This structure was constructed and installed using a manufactured kit. All manufacturers' recommendations were followed. I have read and understand the operation and maintenance requirements associated with this practice. I understand that electrical, heating and mechanical ventilation equipment are not eligible for cost-share as part of this practice.

_____ _____

Participant/Producer Date

Clear Form

NRCS CERTIFICATION

Certifications			
Job Sheet	Prepared by:	Title:	Date:
	Approved by:	Title:	Date:
Installation	**Meets NRCS Standards and Specifications**		
	Certification by:	Title:	Date:

Note: The High Tunnel System will be constructed according to manufacturer's directions. End walls, doors, appropriate cover must be installed prior to certification by NRCS.

University of Kentucky
College of Agriculture, Food and Environment
Cooperative Extension Service

Center for Crop Diversification System Profile
CCD-SP-15

Movable High Tunnels: Opportunities and Challenges for Producers

Krista Jacobsen,[1] Brett Wolff,[2] and Tim Coolong[3]

Introduction

Interest in season extension and high tunnels has grown tremendously in the last decade. High tunnels are appealing for the advantages they bring to early and late production. They can also help to control some pest issues and improve quality. The growth in high tunnels is also partially attributable to support from the USDA-Natural Resource Conservation Service (NRCS) Environmental Quality Incentives Program. At the time of this writing, in Kentucky alone the NRCS has funded the construction of over 1,100 high tunnels through the High Tunnel System Initiative, with more approved and awaiting construction. While high tunnels can be a helpful tool for vegetable growers looking to extend the season or improve crop quality, they also come with their own set of challenges. The purpose of this publication is to describe the opportunities and challenges of movable high tunnel production, with practical examples and experiences from research and commercial farm environments.

Why a movable tunnel?

One of the primary reasons growers may look to movable tunnels is to minimize some of the soil health problems that may occur after a few years of intensive high tunnel production, such as the build-up of fertilizer- and compost-based salts in their soils. These salts are charged particles in soil, typically applied for crop fertility in the form of commercial fertilizers, composts, and manures. In open field production, rainfall helps to leach

An overhead view of the movable tunnels at the UK High Tunnel Research Facility. Each tunnel can be moved to three different positions allowing lots of flexibility in rotations
Photo: Google Earth

nutrients from the soil and pushes salts from fertilizers and other inputs below the rooting zone of the plant. In high tunnels, where rainfall is excluded, these salts can build up in soils and remain in the plant root zone. These salts include positively charged cations, such as sodium (Na^+), potassium (K^+), calcium (Ca^{++}) and magnesium (Mg^{++}), as well as anions such as nitrate (NO_3^-), phosphates ($H_2PO_4^-$), and sulfates (SO_4^{--}). Multiple successive cropping years with high rates of added fertility can result in decreased plant water uptake, stunted growth, or a number of other problems with crop growth and development. Moving the tunnel periodically allows the land to be exposed to rainfall events and flush salinity similar to an open field system. In the high tunnels at the University of Kentucky Horticulture Research Farm, we began to observe soil salt imbalances in our stationary (non-moving) high tunnels after five

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years of production. These salt imbalances have contributed to ripening disorders in our tomato crops to a much greater extent than we see in our movable high tunnels. How big of a problem these salts cause, and how quickly, may vary depending on aspects of soil and crop management, such as irrigation and fertilizer inputs. For more information on managing soil salinity in high tunnels, see the forthcoming High Tunnel Salinity Fact Sheet, available soon.

We should also note that there are management approaches to address these salinity and disease issues in stationary tunnels. These include removing the plastic for an extended period of time to allow precipitation to flush salts out of plant root zones and to expose pathogens to unprotected winter temperatures. Extended irrigation to flush soil salts below the rooting zone is also an option. Yet another option is disassembling and rebuilding your tunnel in a different location periodically. This will be labor intensive, and will put some wear and tear on the structure. Reassembly can be complicated as some parts may be lost, damaged, or worn over time. In addition to the labor and structural considerations, both of these options typically take land out of production. Smaller-scale modular or "caterpillar" tunnels are also growing in popularity and offer the flexibility of a light-weight structure that can be moved around the farm. They are available from several retailers such as Johnny's Selected Seeds.

Moving a high tunnel can also help address some of the challenges of crop rotation in tunnels, where growers may feel compelled to continuously grow high value crops in the same botanical family, such as the nightshade family (e.g. tomatoes, peppers, eggplant, etc.) in the warm season, and cole crops (e.g. kale, cabbage, collards, etc.) or lettuces in the cool season. Moving the tunnel allows growers to avoid repeatedly growing the same crop (such as tomatoes) on the same piece of land season after season, while still allowing them to produce that crop in the tunnel. It also allows the grower to incorporate a cover crop as part of a rotation without taking the tunnel out of production.

Movable tunnels can also add flexibility and increased productivity to a tunnel production plan. As discussed in the "Moving Strategy" section below, a movable tunnel can be used to provide additional heat and protection from rainfall at times when the open field conditions become less favorable. For example, the movable tunnel may be planted in early tomatoes in the spring that carry into the summer months. As temperatures begin to decrease in the early fall, the tunnel can then be moved to cover an adjacent field planted with fall crops such as leafy greens or root crops to extend this harvest through the winter. This allows multiple crops to be in the ground at the same time, with the tunnel moving to whatever crop needs the protection.

Movable tunnels offer opportunities to address high tunnel management challenges without disrupting production and can be very effective tools for sustainable soil management while still extending the season. However, taking full advantage of movable systems requires additional resources and more advanced knowledge of high tunnel production. The following sections discuss some key concepts for productive movable high tunnel management and important design and construction considerations.

Moving Strategy: What are you rotating around?

We have mentioned a variety of reasons why you would want to move your tunnels, but there are several different strategies for timing and frequency of moves. Your decisions on when to move will depend mostly on which variables you are trying to work around. Are you fitting the tunnel move strategically into your in-season rotation (i.e. moving off of spring-summer tomatoes onto a fall crop you hope to overwinter) or are you mainly trying to grow the same crop on a different patch of ground each year? If you have a complex rotation, you may consider moving multiple times per year while other rotations may only require a move once every few years. We have provided a few example rotations on the following page, but you should only use them as a starting point.

Design Elements

Most full-size movable tunnels either use a roller and rail moving system or a ski system. With these moving systems, the anchors are removed from the ground with any additional preparations needed to allow the tunnel to move freely across the ground, and the tunnel is pulled to a new field location. Modular tunnels are more portable tunnels, and are intended to

Example Rotations (3 fields available)

Each row (indicated with blue, green, and orange) represents a snapshot in time. It shows the location of the tunnel and the possible uses of each field in a 3-field setup at 3 different points across 1 season. The tunnel moves left to right across the fields. See overhead view on p. 1 for a photographic representation.

Two moves per year

Winter/Spring	**Field 1 (under tunnel)** Overwintered crops (greens, root veg., strawberries, etc.) planted previous fall.	**Field 2** Cover crop, leave fallow, or use as un-covered field for winter or spring crop.	**Field 3** Cover crop, leave fallow, or use as un-covered field for winter or spring crop.
Spring/Summer	**Field 1** Cover crop, leave fallow, or use as un-covered field for spring/summer crop.	**Field 2 (under tunnel)** Plant early high-value crop after tunnel is moved over field. (tomatoes, peppers, etc.)	**Field 3** Allow cover crop or cash crop to mature. Add cover crop or plant field normally.
Fall/Winter	**Field 1** Cover crop, leave fallow, or use as un-covered field for fall or winter crop.	**Field 2** Continue harvesting high-value crop, cover crop, leave fallow, or plant fall crop.	**Field 3 (under tunnel)** Plant later fall crop (tomatoes, greens, roots, strawberries) before or after move.

Move 1 Early/mid-March

Move 2 Early/mid-September

One move per year

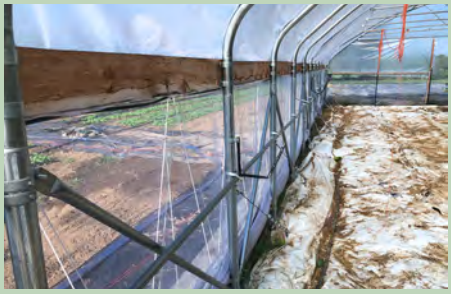
Winter/Spring	**Field 1 (under tunnel)** Overwintered crops (greens, root veg., strawberries, etc.) planted previous fall.	**Field 2** Cover crop, leave fallow, or overwintered outdoor crop (garlic, strawberries)	**Field 3** Cover crop, leave fallow, or overwinter outdoor crop (garlic, strawberries)
Spring/Summer	**Field 1 (under tunnel)** Harvest winter crops, prep beds and plant early high-value crop (tomatoes, pepper, etc.)	**Field 2** Plant spring or summer crop, fallow or cover crop in preparation for fall planting.	**Field 3** Plant spring or summer crops, cover crop, or leave fallow.
Fall/Winter	**Field 1** Cover crop, leave fallow, or use as un-covered field for fall or winter crop.	**Field 2 (under tunnel)** Plant later fall crop (tomatoes, greens, roots, strawberries) before or after move.	**Field 3** Cover crop, plant or fallow. This field will receive the high tunnel NEXT fall.

Move 1 Early/mid-September

Movable Tunnel Grower Profiles *Photos: Brett Wolff and Krista Jacobsen*

Salad Days Farm - Woodford County, KY

Salad Days is an intensive market-gardening operation that uses the movable tunnel for its rotational advantages, and as a way to avoid the buildup of soil pathogens. They bought a robust stationary kit and worked with the manufacturer to add extra bracing and other adaptations to make it a movable tunnel. They generally think that movable tunnels are the way to go unless a farm is land-constrained and cannot move.



For Pete's Sake Farm - Fayette County, KY

For Pete's Sake also operates an intensive market-gardening operation. They have a movable-specific kit they purchased directly from t e manufacturer. The considerable grade of their terrain poses significant cha - lenges. They use movable tunnels because they have limited land, but want their soil to be occasionally uncovered by the tunnel. They typically move twice per year and they think about moving the heat "to the crop."

UK High Tunnel Research Facility (UKHRF) - Fayette County, KY

Since 2011, Dr. Krista Jacobsen has been working with 30' x 72' movable tunnels that were designed and built at the UKHRF. There have been multiple design changes. All the movable tunnels now use wheel and track systems (A); turnbuckle anchors secured to earth augers (trailer anchors, B); and simple curtain panel endwalls, secured with wiggle wire (C). These changes have improved efficiency in moving, decreased wea and tear, and enhanced the experience of moving the structures.

be partially disassembled, picked up, and moved to a new location. There are movable commercial kits available, but some growers may choose to build from scratch or retrofit a stationary tunnel kit to make it move.

Rollers & Rails vs. Skis

Once fully assembled and covered, high tunnels are relatively heavy structures, and it can take considerable

Above: two different kinds of rail system. First a "v" shaped track and second a round pipe rail. Both systems work with casters. Right: the tip of a ski system. This approach uses no rails and instead slides along the ground. *Photos: Brett Wolff*

effort to move tunnels safely and intact. Ski-based systems are available from some manufacturers and generally consist of the tunnel ground posts placed on metal angle. This angle functions as a "ski" which floats over the ground as the tunnel is pulled with one or multiple towing winches. Ski systems are often an affordable way to construct a moving system, as they require little additional modification and the metal angle can be readily available at specialty metal suppliers. However, caution should be exercised when using towing winches, as the tunnels moved this way are more prone to moving unevenly from side-to-side (i.e. one side may move more quickly than the other) and may be more prone to splay outward due to the camber force pushing down on the tunnel. As such, they should be stabilized across the width of the tunnel to limit splay, and great care should be taken with the towing process. It may also be useful to use a winch on each corner post (for a total of 2) to prevent pinching the endwalls in toward each other.

Most commercially available movable tunnels currently being marketed use variations on the roller and rail system. With these systems, a wheel (usually steel) is fixed to the bottom of the ground posts of the tunnels, and the tunnel rolls along tracks of metal, either round or V-shaped to keep the wheel on the track. Because the wheels reduce the amount of friction between the

tunnel and the ground compared to a ski-based system, they are considerably easier to use. At the University of Kentucky Horticulture Research Farm, we are able to move these structures without the use of tractors using as few as six people. The tracks also help limit the outward splay of the tunnel during moving, which causes less wear-and-tear on the structure. However, as roller and rail systems are not flush with the ground, they are more prone to wind entering the structure underneath the toe board and may not be as weather-tight as other systems. Air gaps can be sealed using a variety of materials, including heavy duty plastic or other materials. Once you have decided on the type of moving system, you will need to decide whether you want to buy a commercial movable kit or adapt another kit style.

Buying a commercial kit is the most straightforward option and a number of high tunnel manufacturers now offer movable tunnels. These tunnels are

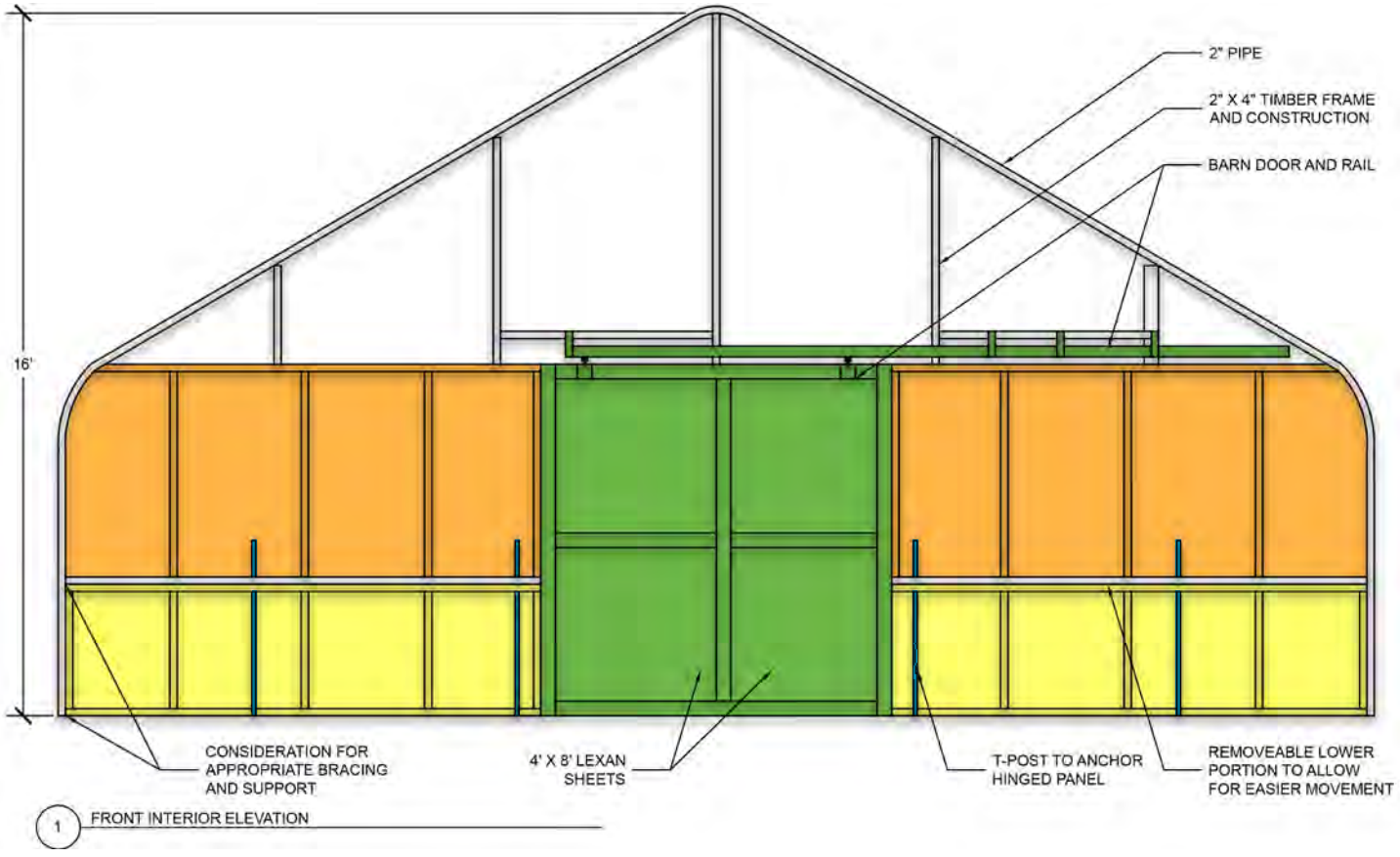
You can see the movable tunnels in action at:
https://youtu.be/dMfwgkBP9-U
Photo: YouTube

designed to move and are built accordingly. If you have any experience with building, then constructing or adapting a kit to move may be an option. Keep in mind that you are taking a kit that is not designed to move and building it to do just that. This approach may require additional bracing and other considerations in addition to the modifications required to move the structure. Moving any structure results in wear and tear on its components and will require ongoing additional maintenance compared to a similar stationary structure. Moving tunnels may reduce the expected life of the structure relative to a typical stationary installation. Consult your manufacturer's policy regarding how modifying the tunnel will affect any warranties.

One note on tunnel size: the authors have seen movable tunnels as long as 200 feet, but that size tunnel will require considerable bracing. Most moveable tunnels are shorter than this. Keep in mind that you'll need flat fields 2-3 times longer than your tunnel so you can move it smoothly.

Anchoring

Once you have moved a tunnel to its desired location, you want to make sure that it doesn't move on its own. Wind is a major consideration even with stationary structures, and since the bows of movable tunnels are not set in the ground, it's even more crucial to plan on a strong anchoring system. There are several options



Endwalls will be one of the major design decisions you will make as you build your movable high tunnel. Some growers use rigid or folding removable panels, while others have opted for a simpler plastic curtain.
Graphic courtesy of Helen Turner, Assistant Professor, University of Kentucky College of Design

available, each with pros and cons. Whether it is from a commercial kit of your own design, movable tunnels are generally attached to an anchor buried in the ground, generally affixed to the toe board or similar point on the structure that is low to the ground.

Anchors are of various strengths, and vary from simple earth or trailer anchors, larger screw-type earth anchors, such as those used to anchor telephone poles, to permanently installed posts made of greenhouse pipe. Anchors run the length of the tunnels, generally every 4-8 feet, and are typically attached using rigid hardware to bind the structure to the anchor, such as turnbuckles or clamps. When considering an anchor system, you should consider whether you want your anchors to stay permanently in place, or to be removed and re-installed each time the tunnel is moved. Removing anchors can be time consuming and physically demanding, though the process can be aided by power machinery. However, having only one set of anchors that moves with the tunnel saves on the cost of additional anchors and allows flexibility to change the location to which the tunnel is moved. The importance of an effective anchor system to protect your tunnel from wind damage cannot be overstated.

A hydraulic-driven tool that drives anchors into the ground and helps remove them can make anchoring easier. You will need the tool and a tractor to power it. *Photo: Tim Coolong*

End Walls

Many high tunnel kits do not come with standard end walls and instead offer end walls as an additional feature. However, most movable high tunnel kits include the end wall in the structure, and have a propriety end wall design specific to their movable high tunnel model. This is because of additional design considerations for end walls on movable tunnels. For movable systems, it is important to remember that as the structure moves, the endwalls will need to clear anything in the tunnel's path. If you plan to move the tunnel onto already planted crops, you will need to account for the plant height, but even if you are moving onto an empty field, you will need to account for seemingly small undulations in grade, unevenness, and high spots. Growers constructing their own end walls should consider these issues of clearance when framing and designing. Several examples of end wall designs are illustrated in the *Movable Tunnel Grower Profiles*.

These designs vary in how rigid or fixed the lower portion of the end wall is. A fully framed end wall, such as those that are raised and lowered on hinges, offers additional structural stability, but may require additional soil work to ensure the end wall is flush to the ground when re-installed. If you are in a site where soil "frost heave" is a consideration, the expansion and contraction of the soil during the winter may put additional pressure on the end wall, particularly at flex points such as hinges. Another option is to finish the bottom of the end wall with greenhouse polyethylene or more durable woven polyethylene curtain material. This allows the bottom of the tunnel to be somewhat uneven and reduce soil disturbance during moves, as well as absorb any changes in soil during freezes. However, this may make the end wall plastic more susceptible to damage by wind or other factors. Care will need to be taken to secure the end wall plastic by burying or through another method.

Costs

Movable tunnels vary greatly in price, depending on how much of the construction and design a grower is considering doing on their own. In general, commercial movable kits cost approximately 50 – 100% more than a standard stationary kit of the same size. However they often include upgraded features that are optional on standard high tunnel kits, such as end walls and additional wind bracing. Stationary kits retrofitted to move may be les expensive. However, this comparison includes only the cost of materials, and not the additional labor for sourcing materials or design work, which may be considerable. Although they may cost more, movable tunnel kits do offer the advantage of designs that have been tested and technical support.

Being able to build the tunnel and grow the crops is only half of the equation. It is crucial that growers considering movable high tunnels evaluate how increases in their production costs may affect their profitabilit . Also, note that movable tunnels may not be eligible for NRCS EQIP funding. Talk to your NRCS service provider about your plans to verify whether your planned tunnel meets their funding requirements.

Conclusion

Movable tunnels may be the right system for a grower looking to take full advantage of the season extension possibilities and help prevent disease and soil health problems that can be associated with stationary high tunnels. This involves careful consideration of crop rotation and timing, as well as some trial-and-error to gain experience with your tunnel at your farm. Growers we have interviewed for this article were generally happy with their decision to go with movable tunnels. One noted that her system of intensive market farming fit well with the movable approach. Both noted increases in quality of their products and their soils, and said that under the right circumstances, they would recommend movable tunnels to others.

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Reviewed by:
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September 2019

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UVM EXTENSION AG ENGINEERING < HTTPS://BLOG.UVM.EDU/CWCALLAH/>

2019-08-14 < HTTPS://BLOG.UVM.EDU/CWCALLAH/2019/08/14/VENTILATION-IN-GREENHOUSES-AND-HIGH-TUNNELS/>

Ventilation in Greenhouses and High Tunnels

BY CHRIS CALLAHAN < HTTPS://BLOG.UVM.EDU/CWCALLAH/AUTHOR/CWCALLAH/>

< http://blog.uvm.edu/cwcallah/2019/08/14/ventilation-in-greenhouses-and-high-tunnels/dscn0553-2/>

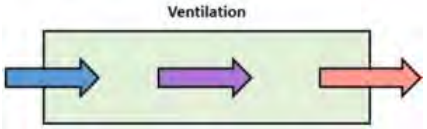
I had the pleasure of facilitating a workshop at the **2019 NOFA-MA Summer Conference < https://nofasummerconference.org/>** about Ventilation in Greenhouses and High Tunnels. It provided an opportunity to collect information from various sources, ground truth observations with growers, and to revisit some fundamentals. The big takeaway, for me, is that there are many, many ways to ventilate a protected culture environment and opportunities for improvement abound. I hope this review provides a framework for troubleshooting some issues that may be common in the field.

Background

Greenhouses and high tunnels provide a protected area for growing vegetables. Greenhouses can be used to start plants and high tunnels can provide season extension. These partially enclosed spaces, however, require attention to climate control. In addition to heating, ventilation and air circulation are important practices that help to provide consistent, well-distributed, healthy conditions for plant growth and production.

Ventilation vs. Circulation

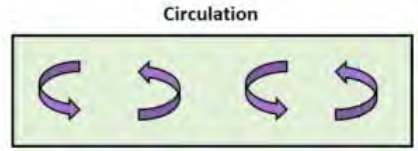
It is important to differentiate two types of air flow that are needed in high tunnels and greenhouses: **ventilation** and **circulation**.



< http://blog.uvm.edu/cwcallah/2019/08/14/ventilation-in-greenhouses-and-high-tunnels/ventilation/>

Ventilation is the exchange of inside air for outside air. This results in exhausting warm, humid air and replenishing it with cooler, drier air. Ventilation strips the humidity and heat from the space using exhaust fans, ridge vents and/or roll-up sides.

Ventilation is the active exchange of inside air for outside air. This exchange is important to remove heat and humidity from inside the structure and replace it with drier, cooler outside air. This also helps to replenish carbon dioxide which is consumed in the process of photosynthesis. Ventilation is accomplished in several ways including end-wall exhaust fans combined with inlet louvers, passive peak vents or ridge vents combined with roll-up sides, roll-up sides alone in an area with reliable crosswind, or even large doors on each endwall.



< http://blog.uvm.edu/cwcallah/2019/08/14/ventilation-in-greenhouses-and-high-tunnels/circulation/>

Circulation is the mixing or stirring of air within the structure. This results in relatively equal conditions being well-distributed throughout the space. Circulation "averages" conditions using HAF fans.

Circulation is mixing the air inside the structure. This is most often accomplished with horizontal air flow (HAF) fans. Circulation is important to ensure each square foot of growing space is getting roughly equivalent growing conditions. HAF's push the air around the growing area and should

ensure that there are no areas without some air flow. These fans help to make up for the limitations of ventilation that often lead to zones of no air flow, typically in the corners.

If you ventilate without circulation, you run the risk of having corners or other zones not benefiting from the exchange of air.

If you circulate without ventilation, you run the risk of having conditions in the structure growing overly hot and humid leading to plant stress and disease.

Passive vs. Active Systems

When considering ventilation of a high tunnel or greenhouse, there are both active and passive options.

Active systems use electric motors to spin fans and move air. Active systems, therefore, require electricity to operate and siting of a high tunnel or greenhouse may impact the feasibility of this. An example of an active system includes two end wall exhaust fans, two inlet louvers on the opposite end wall and a thermostat that opens the louvers and turns the fans on when the temperature is above 85 °F.

< http://blog.uvm.edu/cwcallah/2019/08/14/ventilation-in-greenhouses-and-high-tunnels/dscn0554-2/>

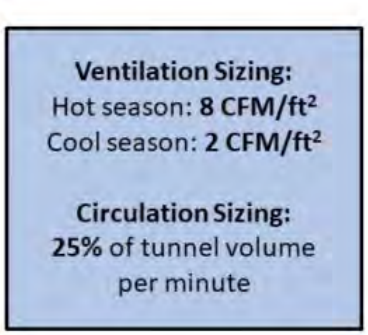
This exhaust fan is used to exchange air between inside the greenhouse and outside. It is run by an electric motor.

Passive systems use openings in the envelope of the structure to allow airflow to happen naturally. Passive systems are often preferred over active systems due to their inherent lower initial cost and energy efficiency and because they offer greater flexibility in siting (e.g. electric utilities are not needed). However, passively ventilated tunnels depend on steady, gentle prevailing winds to assist with ventilation. Avoid siting these tunnels too close to large structures, dense tree lines, or other obstructions that will prevent ventilation.

< http://blog.uvm.edu/cwcallah/2019/08/14/ventilation-in-greenhouses-and-high-tunnels/img_0235/>

A heated greenhouse with manually operated roll-up sides and a ridge vent that provide passive ventilation.

Airflow Requirements

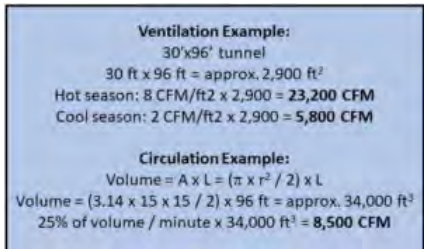


< http://blog.uvm.edu/cwcallah/2019/08/14/ventilation-in-greenhouses-and-high-tunnels/calcs-rules-of-thumb/>

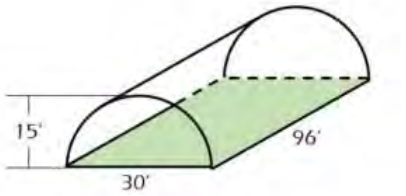
Guidance for ventilation flow rates are provided as volumetric flow of cubic feet per minute (CFM, ft3/min) per square foot of growing area in the publication, **Greenhouse Engineering < http://host31.spidergraphics.com/nra/doc/Fair%20Use%20Web%20PDFs/NRAES-33_Web.pdf>** by Bartok and Aldrich (NRAES-33).

For hot season growing use 8 CFM/ft2 of growing space for cooler season growing use 2 CFM/ft2. For a 30 ft x 96 ft tunnel the total growing area is approximately 2,900 ft2. The hot season ventilation requirement is, therefore 23,200 CFM and the cool season requirement is 5,800 CFM. If a structure is used in both cool and hot seasons, two stages of ventilation can be used with two fans controlled by a two stage thermostat. A variable speed control can also be used to adjust the ventilation flow rate. More resources for winter growing are available on our **Winter Growing < http://blog.uvm.edu/cwcallah/winter-growing/>** page.

Guidance for circulation flow rates is 25% of the overall growing volume per minute (also from Bartok and Aldrich's **Greenhouse Engineering < http://host31.spidergraphics.com/nra/doc/Fair%20Use%20Web%20PDFs/NRAES-33_Web.pdf>**). For a 30 ft x 96 ft tunnel with 15 ft peak, the total volume is approximately 34,000 ft3. One quarter of that volume is approximately 8,500 ft3, so the total HAF flow rate required is 8,500 CFM (ft3/min).



< https://blog.uvm.edu/cwcallah/tunnel-ventilation-figures-revised/>



< https://blog.uvm.edu/cwcallah/2019/08/14/ventilation-in-greenhouses-and-high-tunnels/tunnel-calcs/>

Equipment and Controls

Ventilation Fans & Inlet Louvers

Exhaust ventilation fans can be found in sizes typically ranging from 12" to 48" in diameter, cost $150 to $1,000 each, and provide between 1,000 and 22,000 CFM each respectively. Exhaust fans can be direct drive or belt driven and can be setup to run as single, dual or variable speed. Multiple fans can also be setup with staged temperature controls to achieve at least two levels of ventilation for different growing seasons. Exhaust fans are typically all installed on a common endwall with inlet louvers installed on the opposite endwall to provide sweeping flow. Inlet louvers should be sized with an area equal to the exhaust fans. Motorized louvers with a flange to ensure good sealing are recommended to improve energy efficiency and plant health by reducing drafts. Louvers cost $50 to $250 each.

< http://blog.uvm.edu/cwcallah/2019/08/14/ventilation-in-greenhouses-and-high-tunnels/dscn0553-2/>

Exhaust fans are a common approach to providing active ventilation.

< http://blog.uvm.edu/cwcallah/2019/08/14/ventilation-in-greenhouses-and-high-tunnels/dscn0559-2/>

Motorized louvers can be used to open or close air inlet areas. These are often connected to the same control circuit that run exhaust fans so that the air inlet is opened when the fans are turned on.

Roll-up or Fold-down Sides

Roll-up sides can serve as both inlet and outlet for ventilation depending on the siting, use of other vents and prevailing wind. This method of ventilating is typically accomplished using sheets of plastic that run the length of the tunnel and are rolled up around a pipe to an appropriate degree of opening for the desired conditions. The rolling mechanism can be manual with a simple pipe and tee or can make use of a gear hand crank. Additionally, motorized roll-up motors are available with controllers that automate this task.

< http://blog.uvm.edu/cwcallah/2019/08/14/ventilation-in-greenhouses-and-high-tunnels/img_0287/>

This tunnel has roll-up sides that are adjusted by turning a long pipe. The pipe provides leverage for easier rolling. With each turn, the pipe is slid back through the turnbuckle to make another turn possible.

< http://blog.uvm.edu/cwcallah/2019/08/14/ventilation-in-greenhouses-and-high-tunnels/img_0289-2/>

This tunnel has roll-up sides that are adjusted with a geared hand crank.

It is also possible to achieve the same side venting using a fold-down or roll-down system. Some of these use inflation fans to “blow up” side curtains to seal them closed while others use rope and pulleys to lift or lower the side walls.

< http://blog.uvm.edu/cwcallah/2019/08/14/ventilation-in-greenhouses-and-high-tunnels/img_4582_roll-down/>

This is a fold-down side vent which is managed with a rope and pulley system driven by a motor and controller.

Ridge and Peak Vents

Ridge vents and peak vents are sections of the roof that are designed to open and allow warm, humid air to escape out the top. The differ slightly in their design with ridge vents resulting from one side of the tunnel terminating above the other side at the ridge leaving a vertical section that can be opened or closed. Peak vents are typically a section of roof that runs the length of a gothic type house which can be opened or closed. Both offer an alternative to exhaust fans. When combined with roll-up sides, these vents can provide very effective, quiet, and energy efficiency ventilation. Both are typically easiest and least costly to install when the tunnel or greenhouse is first built. They are operated by a motor and a rack and pinion and can be adjusted to different levels of opening depending on the temperature and the control system.

Gable Vents

Ventilation openings placed high toward the very top of the end wall are called gable vents. These can be effective when combined with roll-up sides as a passive ventilation option.

< http://blog.uvm.edu/cwcallah/2019/08/14/ventilation-in-greenhouses-and-high-tunnels/img_0102/>

Large gable vents, in this case with insect screen, allow for hot, humid air to escape from the top of this tunnel.

Horizontal Air Flow (HAF) Fans

Horizontal air flow (HAF) fans are typically 12" to 24" in diameter, cost $80 to $300 each, and provide between 1,000 and 5,250 CFM each respectively. Some growers have had success using inexpensive box fans, noting that even though they need more of them per house and also need repeated replacements they are less expensive than commercially available HAF's. In either case, it is important to note that HAF fans provide the rated flow for a certain length of "throw." To ensure well-distributed mixing flow throughout the growing area, it is generally recommended to place HAF fans every 50 feet along the length of flow. In practice, especially with dense vegetation in certain crops (e.g. tomato and cucumbers) a maximum distance between HAF fans of 20-30 feet is more appropriate. HAF fans are typically installed in a "race track" layout intended to stimulate flow all around the growing area. This layout does sometimes leave at least two corners with relatively low flow in practice and growers should test the intended layout before finalizing it.

< http://blog.uvm.edu/cwcallah/2019/08/14/ventilation-in-greenhouses-and-high-tunnels/dscn0606/>

Two HAF fans are sufficient for this relatively small propagation house early in the season. There is plenty of open space and very little vegetation to impede flow.

< http://blog.uvm.edu/cwcallah/2019/08/14/ventilation-in-greenhouses-and-high-tunnels/dscn0587/>

This 12" HAF is a very commonly used option that can provide about 1000 CFM of circulation.

< http://blog.uvm.edu/cwcallah/2019/08/14/ventilation-in-greenhouses-and-high-tunnels/img_0243/>

This 30'x96' tunnel is being used for summer tomatoes. The high level of vegetation and a desire for energy efficiency has led this grower to use two shrouded, high throw HAF fans.

Heaters

Although this article is mainly focused on ventilation, heaters are useful for improving the impact of ventilation when humidity control is needed. Heated air can carry more moisture which allows ventilation air flow to reduce humidity more effectively. There are a number of factors involved in sizing a heater for a greenhouse or high tunnel including the size, the desired indoor temperature, the outside temperature, and the envelope of the tunnel. More information about determining heat load for greenhouses and tunnels can be found in the post, **Calculating Greenhouse and High Tunnel Heat Loss < https://blog.uvm.edu/cwcallah/2015/04/01/calculating-greenhouse-and-high-tunnel-heat-loss/>** .

Switches

The most basic controls take the form of switches that turn fans on or off. These are inexpensive and easy to install, but depend on an operator to make changes. It is common to have ventilation fans and HAF fans on separate switches to provide flexibility in their operation.

Thermostats

The next step up is a thermostat, which is a switch that opens or closes automatically based on the temperature that has been set on it. Thermostats can be setup for heating control (close on dropping temperature) or cooling control (close on rising temperature). The sensing probe of the thermostat should ideally be aspirated (air flowing over it), shielded from radiation gain (the increase in heat due to incident sunshine), and located to accurately measure the air temperature the plants are experiencing.

< http://blog.uvm.edu/cwcallah/2016/05/03/thermostats-for-agriculture/img_9656/>

This is a digital thermostat with a long lead wire to the sensing probe.

More information about selecting and using thermostats is available from **John Bartok's article in Greenhouse Management < https://www.greenhousemag.com/article/gm1112-using-thermostats-greenhouses/>** and in our post about **Thermostats for Agriculture < https://www.greenhousemag.com/article/gm1112-using-thermostats-greenhouses/>** .

Wax Cylinders

Wax cylinders can be used to open and close louvers, peak and gable vents when electricity is not available. These sealed cylinders are filled with wax that expands with increasing temperature. That expansion results in increased pressure and moves a piston out. They come in a variety of load ratings and can be adjusted for very specific temperature response. More information about wax cylinders for opening and closing tunnel vents can be

< http://blog.uvm.edu/cwcallah/2017/03/24/improved-ventilation-for-high-tunnels/wax-cylinder-greenhouse-vent-opener-vent-univent/>

Passive wax cylinder louver actuator. [Photo Credit: http://www.littlegreenhouse.com/accessory/vent2.shtml]

found in our post, **Improved Ventilation for High Tunnels < https://blog.uvm.edu/cwcallah/2017/03/24/improved-ventilation-for-high-tunnels/>** .

Integrated Controls

A higher level of control system comes in the form of an integrated control. These systems monitor multiple inputs such as different temperature readings and humidity and control multiple outputs. Previously, these have been considered too expensive for smaller farms or individual tunnels. However, the prices have been reduced significantly. These controls can be helpful for automating more complex high tunnels or greenhouses that include heating systems, ventilation fans, circulation fans, roll-up sides and even irrigation. These systems can generally be accessed from a computer or smartphone for checking conditions and changing setpoints.

Pitfalls, Tips and Tricks

Poor Ventilation

Inadequate ventilation can lead to excessive heat and humidity. High temperatures can lead to plant stress and reduced yield while high humidity can lead to fungal diseases. If you are experiencing high temperatures and have exhaust fans running constantly or have all passive ventilation options completely open, you likely have inadequate ventilation. If you are seeing wide-spread fungal disease, you likely have inadequate ventilation. The

effectiveness of your ventilation system can change over the course of the growing season as increased vegetation introduces more restriction to air flow. You should be able to stand in the middle of the tunnel or greenhouse and feel a comfortable breeze.

Poor Circulation

Inadequate circulation can lead to inconsistent conditions throughout the tunnel or greenhouse. This can show up as hot spots with high temperature, cool spots with low temperature, areas of high humidity, and condensation. Look for leaf movement in every part of the tunnel or greenhouse as a sign that there is air flow present. Strips of survey tape, cut to equal lengths and tied to the tunnel framing to hang down can also be helpful to show where air is flowing and where it is not.

Labor vs Automation

Keeping tabs on a high tunnel or greenhouse can be a real chore that consumes a lot of time and attention often resulting in heightened anxiety. Automating certain controls can reduce the amount of labor required considerably. This convenience and peace of mind comes at a cost, typically $1,500-$2,000 for a controller, sensors and roll-up motors in addition to any fans already in place. With a labor cost of $15 per hour and 15 minutes of labor required per house twice daily, an automated controller will pay for itself in about 250 growing days.

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http://go.uvm.edu/tunnelventilation < http://go.uvm.edu/tunnelventilation>

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A Guide to Preparing High Tunnels for Extreme Weather

Introduction

High tunnels and greenhouses provide protection for crops, extend the growing season, and improve yield and quality. However, climate change brings both a higher frequency and increased intensity of extreme weather events. It is important to think about how high tunnel structures can best be built and modified to endure the extremes. The information below is a summary of experiences shared by the growers of the Vermont Vegetable and Berry Growers Association (VVBGA). Individual grower comments and references for more information are provided following the summary.

Before You Build

Siting

Invest in **site selection** and development before construction begins. Avoid wet or flood prone areas. Build a raised pad for the tunnel that elevates it from surrounding land. This allows for drainage of rain in warm weather and snow melt in colder weather when the ground may be frozen.

Even slightly raised pads can make a big difference by providing intentional drainage for storm water, keeping the growing area more dry.

Before driving in ground posts, **install drainage,** leaving 18-24" of space between a French drain and ground posts. Make sure there is a place for the water to drain to that is not an adjacent field or tunnel. Remember that tunnels shed a lot of water in rainstorms. That water needs somewhere to go quickly.

Leave **room for snow clearing** between and around tunnels. Consider both the room needed for snow clearing equipment and also where the snow will go.

Consider **prevailing winds** and air movement. Site tunnel where there will be good cross ventilation, but not high winds. Plant windbreaks if necessary.

There is plenty of access for snow clearing equipment and room for pushing snow around this tunnel.

Design

Structure

When purchasing a tunnel, choose as much **structural reinforcement** as possible to support snow loads and high winds. Be sure to account for primary crop load (tomatoes, hanging baskets, etc.) This may include the size of structural pipes, number of trusses and truss bracing, wind / corner bracing, and strong purlin to bow connections (cross braces and through-bolting vs. strapping.)

Build **strong end-walls** and make sure they are anchored to the ground to prevent uplift (the upward force that can occur in high wind events). End walls are often the weak point in the design and once they lift or otherwise fail, wind will wreak havoc on the rest of the structure.

A **steeper roof pitch** (6:12 or 26.6°) can promote snow shedding. Even one degree less can make a difference. The gothic shape is designed to shed snow.

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Ventilation

Ventilation fans can push hot air out and draw in cooler and/or less humid air. These systems should be designed well to ensure that they are actively drawing air through the tunnel.

If relying on passive ventilation, install **large openings** for maximum airflow. This starts with high sides for roll up or roll down systems, which may require adding **extended ground posts**.

End walls should have large openings (doors, gable vents).

The roll-up end walls on this tunnel provide access for equipment and also provide additional passive ventilation when needed.

Extended ground posts raise the overall structure providing larger openings for roll-up sides, increasing the volume of air inside, and in this case, adapting the structure to uneven ground.

Ridge vents will optimize passive air flow because heat rises.

Jon Satz was an early adopter of ridge vents due to their passive, quiet nature and their reliability when combined with a greenhouse control system.

Be careful to **avoid mixing passive and mechanical ventilation** at the same time. An exhaust fan running with the sides rolled up will pull air from the path of least resistance (the closest opening of the roll-up side), and may provide little benefit.

For lower cost tunnels without automation, **gable end or butterfly vents** are a good option to improve passive ventilation. These can be easily installed after construction. Consider multiple vents or larger single vents.

Controls

Consider investing in **automated systems and controls** that may respond to changes in temperature, increased wind, and even precipitation more quickly than you can.

Strategies for Existing Structures

Structural Maintenance

Check plastic before anticipated storms. Patch holes, secure wiggle wire, tighten loose areas to reduce flapping .

Check structure seasonally and tighten any loose brackets, replace rotting lumber on endwalls, hipboards, and baseboards. Plumb endwalls as needed.

Rain and Flooding

For tunnels already built, **install drainage**, swales, or other water diversions to steer water away from tunnels. Avoid excavation within 18-24” of ground posts which can reduce their resistance to uplift.

Build **raised beds and use mulched pathways** inside tunnels. Adding organic matter to tunnel soils can improve the "sponging" capacity of the soil and water infiltration. In tunnel walkways, wood chips can help absorb water and reduce compaction.

Raised beds and mulched pathways.

Wind

Shut all the doors and keep the wind out. This may mean extra latches on doors, bracing doors with cinder blocks and rebar, tying down roll-up sides, securing louvers and ridge vents, etc.

Patch all plastic tears and check wiggle wire fastening.

Add extra trusses and bracing. Some growers have trusses added to every bow and invest in additional wind or corner bracing.

Strapping over bows that attach at the ground posts can help prevent uplift in high winds.

Growers in areas subject to frequent, high winds and storms have started installing straps over bows. These straps connect to a cable that is threaded through eye-bolts at the ground posts and prevent the plastic from lifting.

Snow

Double layer, inflated plastic helps shed snow.

Consider temporary bracing with 2x4 posts under hoops especially in Quonset hut style tunnels or those with weaker hoops.

Clear snow evenly from both sides, a little bit at a time, to prevent eccentric loading on the bows (takes longer, but may prevent damage).

Heat the house to melt snow as it falls. Heating the house, even minimally, can prevent accumulation of snow and minimize snow clearing needed.

Gear up! Consider getting a snow shovel with an extra-long handle, a wide long handled broom with soft bristles, and a good pair of snowshoes.

Heat

Use shade to keep crops cool. Use 30% shade cloth. Research shows that white shade cloth allows more plant available light through but for short durations, black is effective too.

Black (top) and white (bottom) shade cloth both provide some reduction of heat gain from incident solar radiation.

Coating the exterior of the tunnel with a washable material provides temporary cooling. Surround WP, lime, or Koolray are recommended.

Lighter colored mulches help cool the soil such as straw, white landscape fabric or white plastic. Mulches can also help keep soil evenly moist during hot periods.

Moving air through the tunnel helps plants stay cool. Passive ventilation such as roll up sides, butterfly vents, and doors should be fully open during hot stretches. See above for design guidance.

Taller ground posts (extra roll-up side area) can improve passive ventilation flow rate. This also provides more flow area to compensate for restricted air flow due to any insect netting.

Ventilation fans can push hot air out and draw in cooler and/or less humid air. See above for design guidance.

Circulation fans such as horizontal air flow fans (HAF) or vertical air flow fans (VAF) move air through crops which helps keep plants cool, reduces humidity, and disease, and can increase pollination during hot humid stretches. See above for design guidance.

To reduce plant stress during hot periods, be sure to keep plants well-watered; do so during cooler times of the day. Check the soil regularly to make sure it is moist.

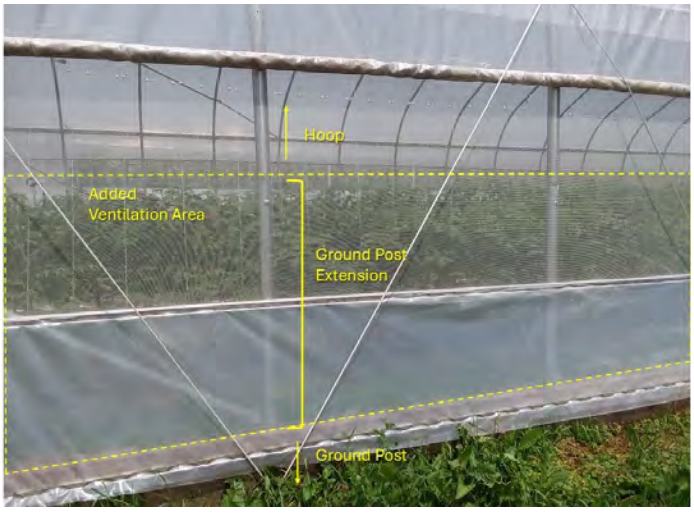
Adjust horticultural practices. For crops that are prone to sunscald or sunburn, do not prune the leaves or suckers directly above fruit and expose it to direct sunlight. Reduce pruning stress during hot periods.

Only use insect netting if necessary for crop production; it can reduce airflow and increase tunnel temperatures. If using netting, use the largest mesh opening possible to exclude the target pest(s) and increase airflow area and ventilation accordingly.

Consider worker safety. If the tunnels are too hot for plants, they are too hot for humans. Shift the hours spent working in tunnels to early mornings and cool evenings to reduce stress on workers.

When retrofitting perimeter insulation take care to angle the excavation away from the ground posts to avoid soil disturbance which could loosen them and reduce uplift resistance.

(Above) This tunnel was retrofitted with insect netting to exclude striped cucumber beetles. Note the two large ventilation openings above the (normally closed) doors, purposely sized to provide as much area as possible for passive ventilation due to the added air flow resistance resulting from netting. (Below) Extended ground posts provide additional area when netting is installed behind roll-up sides.



Grower Experiences

Original Question

There have been loads of listserv exchanges about tunnels in severe weather conditions. I've scanned the archives and am drafting a resource that brings much of that experience together in one place.

Grower Responses

Excessive Rain / Flooding

- I just walked some of our fields again today. Like last year, they are soaked enough I cannot put a tractor with ag tires on it unless I want all sorts of ruts. That reminded me of travelling in Holland and seeing acres of land under continuous glass houses there. With our continuing spring to early summer rains and fall to earl winter rains perhaps we are going to have to do the same thing with plastic they are doing with glass.

- All of those issues you've listed should be addressed before construction. Lots of water comes off a greenhouse in a heavy rain. Where's it going to go? You can channel gutters into underground PVC and divert the flow to a grassy spot or use a dry well.

- French drain all around the GH! Fill the trench with coarse material so the water goes rapidly to the drain. Make sure the terrain has been sloped so the water does not stay around the greenhouse. This will also prevent cold thawing snow to enter the GH in the spring, really reducing soil temperature on the sides. You really have to be careful during construction so the anchors of the GH are in undisturbed soil (closest to the trench of the drain as possible) or that you reach proctor compaction test required by the manufacturer.

- Actually I started with structure but I'm going to go back to site work to strategically divert water in heavy rainfalls. We're moving one tunnel that water likes to run into, and I'm thankful that we had a good excavator operator who sited our tunnels well.

- All my tunnels are above grade. I can't believe anyone would build a tunnel on grade unless adding positive drainage in some form, ditch or tile. The number on question i get from other growers is "how do i keep my tunnel dry?" And my answer is "Do anything, just don't do nothing!"

- [from MIKE BISOGNO, RIMOL] Site selection is key to prevent damage from rain and flooding. Do your due diligence to ensure your site has good drainage and is not in a flood risk zone. A French drain or swale drain system dug around the outside of your tunnel can help with drainage.

- [from MIKE BISOGNO, RIMOL] Polycarbonate baseboards hold up better against water damage. Wooden baseboards will rot over time and can cause rain to backfill into your tunnel if they are not dug deep enough into the ground.

Strong Wind

- I put straps over my plastic every other bow. All the farms in Asia have straps over the high tunnels. I've been meaning to send pictures and hopefully will get to that soon.

- When we bought our first gutter connect I had it engineered for 80 mph winds and peak to peak snow load. When we get cheaper tunnels, we get trusses every bow and extra wind bracing.

- [Strong Wind and Heavy Snow] Our best strategy for this is buying tunnels from Ledgewood or other places that sell hefty frames with substantial wind kits.

- We did have a tree fall on a tunnel last season. It damaged the plastic and bent the frame but we were able to roll the tree right off the structure and used the wood to make a garden bed alongside the tunnel. This was a home-bent greenhouse from top rail fencing.

- make sure there is no holes in which wind can enter the greenhouse! There are some wind/rain sensor that can close rollups and roofs if there is too much wind. Windbreaks also does a great job of reducing wind speed, make sure they don't shade the GH. Mine were planted in 2012 and really... It works! Great investment!!!

- For high winds the most important thing is to shut all the doors and keep the wind out!

- … we start with the structure. Has to be burly to withstand wind and snow. We like Ledgewood, Rimol or Harnois. We also like an extra tall tunnel like the taller posts that Ed from Ledgewood offers, which provides both more space for snow to fall off the roof (read, less plowing) and more side ventilation in the heat. We also like a double layer, inflated tunnel because it helps A LOT with shedding snow and increasingly, ice. Two layers also help reduce friction caused by plastic rubbing on poles in the wind.

- Wind, we close the corners up with wiggle wire, and secure all doors.

- We have an Ed Persons [LEDGEWOOD] house. It has survived hurricanes. We close it up tight. We tie the roll up sides tightly together so they do not flap at all during storms.

- Wiggle wire down roll up sides, brace doors cinder blocks/ rebar.

- [from MIKE BISOGNO, RIMOL] Tunnel design is critical for standing up to high winds. Some key design elements to look for include: a truss and truss brace on every bow; wind bracing on all four corners; and a strong

purlin-to-bow connection (such as a cross-connector rather than a two-hole pipe strap or through-bolted).

- [from MIKE BISOGNO, RIMOL] We recommend closing up the tunnel during high winds. Wind can damage anything that is not secured. End wall framing and doors can be a weak point. We highly recommend strong end wall framing that is secured in the ground. Failure of an end wall can let wind rush in and act as a scoop, pulling the ground posts out of the ground.

- [from MIKE BISOGNO, RIMOL] If you are at elevation, you may also want to consider a shorter structure. The taller your tunnel, the more wind will be an issue.

- [from MIKE BISOGNO, RIMOL] Tunnel maintenance is also important to protect against wind damage. Regularly do a perimeter walk to make sure the rope system for your roll-up sides is taut and your poly is locked in place and does not have any tears.

Heavy Snow

- Snow is not as much of an issue as it used to be but there still is an occasional heavy, wet storm. Don't buy a greenhouse from down south unless you can dictate the structure's construction needs. You don't have to buy one off the shelf.

- Specifically for snow, we snowblow around the tunnels and try to maintain the same paths all winter. During or after a storm, we snowblow the paths, pull the snow off the greenhouses with a cushioned snow rake and re-blow the paths. Haven't had to do this much in the last two winters.

- Also using the snow removal strategy that Ed [Person, of Ledgewood] always shares about pulling a little bit of the snow off from the middle of one side and then going around and doing the same thing on the other side. It takes forever.

- I have lots to say about snow managing on the GH! Here we have 2 layers of plastic inflated. There is 2 solutions: first: heat so the snow melts as it is falling, second: shovel. Heating costs a lot and I am questioning about the environmental impact. BUT it is the best way to manage freezing rain that will rip your GH plastic as soon as the wind will lift the ice plates. Shovelling is hard on plastic and you need to be carefull!. Make sure there is a certain balance in snow load on each side of the greenhouse so the snow load does not push de GH on one side. In multichapel GH I find electric heating cable in the gutter does a good job in freeing the path so the melting snow can evacuate. You cannot rely only on the heating cable to melt all the snow in the gutter. The snow around the heating cable will melt creating a tunnel so you need to climb up there to break the tunnel so there can be contact between the heating cable and the snow/ice. You also need to climb up there and push the snow with a sleigh shovel all the way to the end (and the beginning) of the gutter. What has made the biggest difference here is to first free the south side so the sun can get into the GH and help to melt the snow on the roof (my multichapel are east-west). When snow has started to melt it creates a fine layer of ice and it is much easier to remove big chunks of snow. That way you can fill your shovel with 2-3 times more snow which reduces by 2-3 times the time you spend pushing the snow to the end of the gutter.

- Buy roof snow shovels with long extensions [and a] good pair of snow shoes!

- [from MIKE BISOGNO, RIMOL] Consider snow drift when choosing your high tunnel site. If you have multiple tunnels, space them out as much as possible (ideally 12' or more apart if snow removal is needed) so there is room for snow to slide off and build up. Don't build too close to a barn or other structure that could drop snow or ice onto your tunnel.

- [from MIKE BISOGNO, RIMOL] Tunnels with steeper roof pitch will hold up better against heavy snow; look for a 6/12 roof pitch for optimal snow shed. Even one degree less can make a difference. The gothic shape is designed to shed snow.

- [from MIKE BISOGNO, RIMOL] Do not let snow build up along the sides of your greenhouse – keeping the sides cleared will make sure the snow on the roof has a place to slide.

- [from MIKE BISOGNO, RIMOL] A 36-inch, soft bristle shop broom works well for clearing snow from poly. Use the brush to bounce the poly between bows, which will help snow naturally drift off and minimize the risk of tearing.

[from MIKE BISOGNO, RIMOL] As extreme weather increases, so do engineering standards. Ask your tunnel manufacturer for engineering data around snow/wind loads.

High Heat

- Long-term: planting grapes along the edges of the tunnel. I know this is a weird one that's impractical for many but we're excited by what we've been doing for the past 3 years in our coldframe. Grapes don't leaf out until mid-June so they're not going to cool down the space in spring (when we want it to heat up - except for those 90 degree days we've been getting in May). They are easy to trellis/prune and this process generally happens in early spring and fall. Their canopy hangs up at the cross-ties for us. It took about 2 years for them to get large

enough to shade the space. This is still a new thing for us and we're learning as we go but it looks promising because it doesn't involve plastic shade cloth, much maintenance during the main growing season and could yield us a saleable crop. We started with concord-like table varieties that are proven in this zone but are starting to plant warmer (and tastier) varieties.

- Other strategies: we're no longer using plastic ground cloth and that has helped keep the spaces cooler. We mulch with straw in the beds and use wood chips in the pathways.

- Hard to get temperature inside tunnel lower than outside temperature. I would say adjust irrigation to make sure plants do not suffer any water stress during these conditions. The plants will reduce tunnel temperature by evapotranspiration. Opening roof on the greenhouses really does a great job of letting the hot lighter air get out. Never tried shadecloth. I think the key is irrigation and making sure your GH is filled with plants.

- For hot weather we spray Kool ray paint over the greenhouses and tunnels, it really cuts the extreme heat and washes off with the first snows. Environmental safe as well…

- Ventilation and air movement feels essential for all times of year, I don't know if that is really extremes, but I wouldn't consider building a tunnel if we couldn't run power for circulation fans.

- Then there's shade cloth. We're slowly building up our supply so that we can toss 30% shade over production tunnels and 50% over our propagation house.

- Then irrigation. Essential always, but it's been really helpful to install timers in all of our tunnels so that we can increase frequency of watering during heat waves without having to go out and do it manually. Cucumbers especially respond poorly if underwatered during heat.

- [from ED PERSON, LEDGEWOOD] High heat events are difficult to mitigate but there are some things that can help reduce damage. Make sure that roll up sides are rolling completely to the hip board and that they roll up evenly from end to end. It might be a broken screw holding the roll up pipe together, clips that failed from age or poor installation.

- [from ED PERSON, LEDGEWOOD] Make sure that irrigation systems are working properly and boost watering to help the plants take up as much water as possible.

- [from ED PERSON, LEDGEWOOD] Low percentage shade cloth can help reduce heat and light stress. Short term use is all that is needed in most cases. Shade can cause stretching of plants and slowed maturity of some plants.

- I would love to learn more about warm climate growers who are growing lettuces in shade houses and how this practice can be adapted to New England— what % shade cloth should we be using for tunnel lettuces/ greens in June/ July/ august? The disease pressure after these weeks with 3" of rain is just too high…. Love being able to control water in my tunnel but need to invest in shade.

- Every tunnel has overhead irrigation in the frame above. So, we often use overhead to wet things, just 10 minutes, maybe a few times a day. EVEN FULL-GROWN TOMATOES! They do dry again! People needn't be so paranoid about wet, that they lose flowers and fruit.

- We use shade cloth. 30% on everything. Some years it is on for months, some years it is on for days. This year, it was on for 3 days, and currently is off. I can't believe people do not just own shade cloth for every tunnel. It is so cheap. Our days are long!! in summer. Your plants can afford the lack of photons.

- [from MIKE BISOGNO, RIMOL] Tunnels with high sidewalls (6') cool most effectively.

- [from MIKE BISOGNO, RIMOL] A ridge vent can provide additional ventilation and can get you as close to outside air temperatures as possible. An environmental control system and/or automated roll-up sides can also make cooling more efficient and timely. These can be added onto existing tunnels and may be eligible for NRCS funding as part of the On-Farm Energy Initiative program (ask about CPS code 374).

- [from MIKE BISOGNO, RIMOL] Sunlight and heat degrade poly over time. Regularly replace your poly to ensure its UV blocking properties are working optimally.

- [from MIKE BISOGNO, RIMOL] If you're using shade cloth, look for white shade cloth rather than black– it will keep the tunnel cool while still letting in light that your plants need. Using a double wire lock system for roll-up sides facilitates the easy addition of shade cloth.

<u>Other</u>

- Computers are great teamed with weather stations if you can afford them as they work if you're not there.

- …the best investment I ever made was an automatic generator!

- We have some goals of minimizing plastic and using wood where ever possible - this makes repairs and disposal easier and cheaper. Since damage to tunnels is a

given (through wear and tear or extreme weather) using materials that are easy to work with, don't require special skills or tools and can be composted (like wood, straw,etc) helps us recover from damage.

- It is stupid to say but it is important to inspect the structures every year or once every 2 years (who really take time to do that). Having constructed all my GH myself (including the multichapel) really gave me a profound understanding of how they are made which really help troubleshooting/preventing any problems (so far). BUT I have a personal interest in doing so and the time spent doing this was not spent doing other things that might have been more productive or lucrative (opportunity costs). Having some kind of middle size farm, I can hire a person that is responsible for infrastructure maintenance (or hire somebody to manage the fields crop while I do the maintenance).

- Our main tunnel was bought used many years ago and has given us no problems. It has roll-up sides AND an exhaust fan that runs a lot these days, which I think helps to prevent overheating. We shut it down for the winter so there is no heat. Double poly cover with inflation fan seems to keep snow from collapsing the thing- we have maybe become lackadaisical but we don't shovel or plow there sides any more just let snow build up and slide off.

- For extremes we think about heat, snow, wind to some extent, and mitigating quick weather or temperature swings (think a cold snap in early spring)

- I'm also thinking a lot about people management in tunnels. We don't typically get to field work until after harvesting, but I can't send people out to trellis in those hot temperatures, so having an SOP regarding working in the heat or starting work earlier, which is tough with a remote workforce (that has to commute).

- One thing that feels more frequent with the weather swings is power outages. The winds and snows (especially the wet snows we've been having in recent years) are adept at knocking power out, so we've had to be sure we have a generator on hand and backup heat for tunnels. Backup heat is also helpful for those springtime cold snaps.

- I'm SUPER CURIOUS about using the heat socks popular in Canada for creating some sort of movable low input heating system to help mitigate those cold snaps. Like an electric garage heater hooked up to a heat sock that you can put in whatever tunnel happens to have your tomato crop. Lower cost than installing a propane heater, and movable to promote crop rotation. You know, in case you're looking for a project or something. :)

- We have been building 18'X12' end of GH leanto's. They are short of the peak by 4' so we can build end wall peak vents to get rid of heat buildup... we try to send a photo. all the best.

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Available on the web at go.uvm.edu/**extremetunnels** or by pointing your phone's camera at the QR code at left and clicking on the link.

Ag ENGINEERING

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CROP MANAGEMENT

Water Management for Vegetable Crops on Small Farms

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Introduction

Water management is critical in vegetable farming, regardless of farm size and crop type. Both inadequate and excessive water can lead to issues, with the extent of damage influenced by environmental conditions, soil properties and plant characteristics. This publication aims to help small-scale and diversified vegetable farms improve their water management practices for both open-field and high-tunnel production. While this content is intended for Indiana farmers, the information may also be relevant to growers in other humid and temperate regions.

Chapter 1. Common Vegetable Crops' Responses to Water Stress

Plants experiencing water stress — whether from too little or too much water — appear less healthy, become more susceptible to diseases and pests, and produce lower yields and unmarketable produce. Extreme water stress can lead to a complete crop loss. While various factors may prevent plants from achieving their maximum economic value, poor water management is often one of the most significant issues limiting crop yields at small farms.

Poor Water Management Leads to Unhealthy Plants

Insufficient water supply leads to drought, which progresses in stages. In the early stages, when the transpiration demand is high and roots cannot absorb water fast enough to meet the plant's needs, the stomata in the leaves close to conserve moisture. When stomata close, photosynthesis halts in most plants. Once conditions improve, the stomata reopen, and photosynthesis can resume within minutes. Over extended periods of drought, plants adapt by altering root growth, with drought-tolerant crops often developing deeper roots. This allows them to access water stored deeper in the soil, helping them recover and resume normal water and nutrient uptake, as well as their usual growth rate.

However, if drought continues, photosynthesis begins to decline significantly. Prolonged stress slows the development of new leaves and shoots, and existing leaves show signs of poor health, including nutrient deficiencies, increased susceptibility to diseases and pests, and wilting (Figures 1 and 2).

Too much water can also cause plant wilt, stunted growth and yellowing, similar to drought-related above-ground symptoms. When soil becomes waterlogged, oxygen is displaced from soil pores, creating an oxygen-deficient environment. This lack of oxygen inhibits root respiration and damages the roots. Damaged roots cannot supply the water needed for transpiration, so

Figure 1. *Broccoli plants exhibiting poor stand, slow growth, and leaf yellowing as a result of drought stress.*

Figure 2. *Comparison of peppers grown under deficient water supply (left row) and optimal water supply (right row) in a high tunnel.*

the stomata in leaves close and leaves wilt. Additionally, oxygen deficiency significantly reduces photosynthesis, decreases chlorophyll content, and accelerates leaf senescence, resulting in leaf yellowing (Figures 3-5). The injured root systems are also more susceptible to soil pathogens.

It's important to note that deep-rooted vegetable crops may recover quickly from extended drought once adequate water is restored. However, waterlogging for a few days can cause permanent root damage, which may limit the crops' productivity even after environmental conditions improve.

Figure 3. *The response of tomato plants to waterlogging. In the picture, the three tomato plants on the left experienced waterlogging; the three plants on the right grew under optimal conditions during the same period. The stressed plants exhibit wilting, yellowing and stunted growth.*

Figure 4. *The summer squash plants showed yellowing leaves when waterlogged.*

Figure 5. *Pepper plants wilted after an excessive rainfall.*

Figure 6. *Poor spinach seed germination at the near end of this bed.*

Figure 7. *Flower bud or early fruit abortion of pumpkins might be caused by drought stress.*

Poor Water Management Leads to Uneven Seed Germination

For directly seeded crops, such as salad greens, spinach, root crops, sweet corn and direct-seeded pumpkins, evenly distributed and adequate soil moisture is crucial for seed germination and uniform crop growth (Figure 6). Poor seed germination not only wastes seeds but also encourages weed growth due to the resulting uneven stand. Additionally, uneven crop growth caused by delayed germination complicates subsequent crop management. Ensuring proper soil moisture is essential for successful seed germination, which is the critical first step in growing direct-seeded crops.

Poor Water Management Delays Harvest and Reduces Yield

Insufficient water during flowering and fruit-setting stage can severely disrupt pollination and early fruit development, leading to flower bud abortion, poor or failed pollination, early fruit drop, and premature ripening (Figures 7 and 8). Although additional fruit may set after adequate water becomes available, losing early fruit set will delay harvest and lead to economic losses.

Figure 8. Misshaped fruit observed in a watermelon field suffering from severe drought.

Figure 9. Different stages of blossom end rot in tomatoes.

Figure 10. Different stages of blossom end rot in peppers.

Figure 11. Blossom end rot of watermelon.

It is important to note that deficient water supply is not the only factor that can cause flower and fruit abortion and misshaped fruit. A lack of pollinators, inadequate pollen, adverse weather conditions, poor overall plant health, and nutrient deficiency or excessiveness can also cause fruit abortion.

For fruiting vegetables such as watermelons, melons, and pumpkins, insufficient water not only affects fruit set but also leads to smaller fruit when drought occurs during fruit expansion, which negatively impacts yield.

A lack of water slows root expansion in root crops like carrots, beets and radishes. In leafy crops like lettuce and Asian greens, a reduced water supply stunts leaf growth. The end result can be a decrease in yield and income, either because the crop is harvested at a smaller size, or takes longer to reach the desired size, resulting in slower turnover rate of crops on one bed.

Poor Water Management Leads to Unmarketable Fruit and Reduced Quality

Water stress causes physiological disorders in fruits, reducing their marketability, which can lead to significant economic losses. One of the most noticeable fruit disorders related to water stress is blossom end rot (BER), frequently seen in tomatoes and peppers, and occasionally in watermelons (Figures 9-11). BER initially appears as a small dark or water-soaked area at the blossom end of the fruit. This spot darkens, enlarges, and dries out as the fruit matures. The fruit becomes unmarketable. Additionally, saprophytic pathogens may colonize the affected area, leading to fruit rot.

The direct cause of BER is a calcium deficiency in the developing fruit. However, a lack of calcium in the soil is rarely the key factor leading to BER. Calcium moves into plant roots with water, and moves from roots to shoots and developing fruits with water. The driving force for water movement is transpiration, and leaves demand much more water than developing fruit. When transpiration is inhibited even a little, developing fruit will receive a reduced amount of calcium along with the reduced water supply compared to leaves, because leaves have a stronger pull on the water than fruit. So, when transpiration is inhibited — whether due to limited water supply or diseases — it can lead to BER even with sufficient calcium in the soil. When tomatoes are grown in natural soil, BER is more commonly associated with deficient water supply than with other factors in Indiana.

As tomatoes and peppers set fruit over a long period of time, BER can occur at any time from the first fruit set until toward the end of the season, whenever stress conditions take place. In peppers, direct exposure to sunlight and high temperatures can cause sunburn, with symptoms similar to BER (Figure 12). Distinguishing between these factors can be challenging. However, the most dramatic damage of sunburn typically occurs under dry conditions combined with high temperatures or sun exposure.

Figure 12. *When the symptom occurred on the sun exposure side, the symptom is more likely caused by sunburn rather than BER.*

Ripening tomatoes and melons may crack or split when plants are suddenly exposed to excessive water, especially after an extended dry period. This physiological disorder is related to a rapid uptake of water by the fruit. The fast water uptake affects the strength and elasticity of the fruit skin, resulting in skin breaking (Figures 13-15).

Figure 13. *Severe tomato fruit cracking observed after heavy rains.*

Figure 14. *Cracking on tomato fruit observed following an extended irrigation event.*

Figure 15. *Watermelon fruit split after heavy rains.*

Figure 16. *Water-soaking observed on the edge of the watermelon flesh. The symptom is often observed after heavy rains at fruit ripening.*

In addition to external damage that makes fruit unmarketable, excessive water during the fruit ripening stages may reduce fruit sugar content and cause ripening disorders that reduce the internal fruit quality (Figure 16).

Priorities in Irrigation Management at Small and Diversified Vegetable Farms

Most small-scale vegetable farms grow a wide variety of crops, requiring farmers to juggle planting, harvesting and various crop management tasks. As a result, it can be challenging for farmers to dedicate sufficient attention to the irrigation needs of every crop. Additionally, small farms often have limited irrigation

capacity. Therefore, understanding how to prioritize irrigation management is crucial for maximizing overall efficiency at small farms.

To plan irrigation on small farms, a top priority should be placed on ensuring adequate soil moisture for germinating direct-seeded crops. If soil is moist, irrigation may not be needed. If not, soil should be thoroughly watered after seeding, with careful attention to prevent the germination zone from drying out. If a crust develops on the soil surface and prevents emergence, a light irrigation applied slowly can soften the crust to allow emergence.

In addition to soil moisture, temperature is another crucial factor affecting seed germination. Depending on the season, the temperature of the irrigation water — whether too warm or too cold — should be considered, especially for temperature-sensitive crops. More information about irrigation water quality is discussed in Chapter 5.

Newly germinated seeds and recently planted transplants have shallow roots, making them vulnerable to both excessively dry and overly wet topsoil conditions. It is generally more desirable to start with plenty of moisture in the soil before transplanting, rather than to try to wet the soil afterward. This approach ensures ample water is stored in the soil to support healthy root development, while reducing the risk of waterlogging in young plants. Even with plenty of moisture in the soil at the beginning, applying

Table 1. *Vegetable crops and growth period most critical for irrigation requirements.*

Crop	Most Critical Periods
Broccoli, cabbage, cauliflower, lettuce	head development
Carrot, radish, beet, turnip	root enlargement
Sweet corn	silking, tasseling, and ear development
*Cucumber, eggplant, pepper, tomato, melon, watermelon	flowering, fruit set, and fruit development
Bean, pea	flowering, fruit set, and development
Onion	bulb development
Potato	tuber set and enlargement

This table is adapted from Midwest Vegetable Production Guide (mwvguide.org)

* For continuously flowering plants such as tomatoes, peppers and cucumbers, the critical irrigation period extends through most of the growing season.

Sidebar 1. *Vegetable crops vary in the susceptibility to natural water fluctuations*

Vegetable crops vary in their susceptibility to natural fluctuations in water availability, with some suffering greater economic losses than others. In 2022, we conducted a demonstration comparing the growth of tomatoes, peppers, and eggplants under irrigated and non-irrigated conditions at two locations in Indiana: The Southwest Purdue Agricultural Center (SWPAC) in Vincennes and the Pinney Purdue Agricultural Center (PPAC) in Wanatah. At both locations, crops were grown on plastic-covered beds, with irrigation provided through a single drip tape placed beneath the plastic mulch. In irrigated plots, water was applied daily as needed to maintain optimal soil moisture in the top foot of soil under the drip tape throughout the monitoring period.

At SWPAC, plants grown without irrigation experienced significant drought for most of the season, leading to substantial yield reductions. Marketable yield of tomatoes, in particular, decreased by 73% compared to those grown on irrigated beds, while pepper and eggplant yields declined by 17% and 20%, respectively. At PPAC, drought was less severe, resulting in higher overall crop yields than at SWPAC. Nevertheless, the absence of irrigation still caused yield losses in all three crops, with peppers experiencing the greatest marketable yield reduction at 37%. Despite Indiana often receiving adequate precipitation, erratic rainfall distribution makes irrigation essential for achieving acceptable yields in fresh-market tomatoes, peppers, and eggplants.

However, it is not uncommon for watermelons to be grown on dry land in southern Indiana. A three-year study comparing seedless watermelons grown on irrigated and non-irrigated lands revealed that, although plants grown on dry land exhibited smaller vine coverage during drought periods, a yield reduction, approximately 16%, occurred in only one of the three years. In the other two years, yields were comparable between the irrigated and non-irrigated conditions. This study indicates that watermelons generally tolerate natural fluctuations in water availability, and in most years, yield may not increase with irrigation in Indiana.

a small amount of water and fertilizer solution to each transplant at transplanting or shortly after planting is recommended.

Close attention should be given to high-value crops during critical irrigation periods, as fluctuations in soil moisture can greatly impact both yield and marketability (Table 1). It is important to note that susceptibility to water-related disorders varies among cultivars. For instance, cherry tomatoes rarely experience BER, while fruits of certain slicer tomatoes and Roma tomatoes may often develop BER, and some heirloom tomato cultivars are particularly prone to splitting as they ripen. Farmers should consider the specific water sensitivities of different cultivars and apply tailored water management practices accordingly.

During the early growth stage of fruiting vegetables, plants are generally more tolerant of drought. Moderate drought can encourage deeper root growth, resulting in more resilient plants later in the season. At the final fruit-ripening stage, when the fruit has reached its full size and is undergoing chemical changes to enhance flavor, color, and aroma, reducing water supply can actually benefit flavor development. Drier conditions are often preferable during these phases.

Chapter 2. Principles of Water Management on Small Farms

Annual precipitation in Indiana generally meets the water needs of most crops. However, the erratic distribution of rainfall throughout the growing season makes effective water management essential when producing crops as a business. This management must address both drought conditions and the risks of excessive water after heavy rains.

A deep understanding of soil and its relationship with water is critical for successful water management. The rate of water infiltration into the soil determines how quickly water is absorbed and the likelihood of waterlogging or runoff after significant rainfall. The soil's water-holding capacity determines the maximum amount of water it can retain after heavy rainfall, the upper limit for water application during a single irrigation event, and the desired frequency of irrigation. Key soil characteristics — texture, structure, slope, organic matter content, compaction, and water table — collectively influence the soil-water relationship and play a crucial role in effective water management.

Managing Excessive Water

Natural soil properties and field topography are fundamental for water infiltration and drainage and determine the risk of waterlogging at a given location. While the type of soil is hard to change, various approaches to improve soil health, such as cover cropping and reduced tillage, can enhance water infiltration and drainage of naturally poorly drained soils. Additionally, understanding the farm's topography and incorporating a well-designed water drainage system early in the planning stages can be highly effective in directing surface water away from crop areas, thereby reducing the risk of waterlogging and enhancing crop production.

Figure 17. *Rainwater seeping into a high tunnel from the sides.*

High tunnel and caterpillar tunnels are commonly used on small farms. While these structures prevent rainfall from reaching the crops directly, the water that runs off the plastic accumulates within a few inches of the tunnel edges. If this excess water is not redirected, it can seep into the high tunnel, complicating water management (Figure 17). In cases where irrigation falls short of meeting crop water needs inside the high tunnels, water entering from the tunnel sides may benefit crop growth, leading to better plant performance of the side rows. However, when ample irrigation has already been provided, excess water from outside the tunnel could potentially cause waterlogging on the side rows. This issue can be easily overlooked because the waterlogging

Sidebar 2. *Estimating Plant Water Needs*

Estimating plant water needs is based on the estimated water use by a non-stressed, well-watered grass or alfalfa crop that completely covers the ground, plus evaporation. The estimate of plant water use plus evaporation is called reference or potential evapotranspiration, abbreviated PET. PET is calculated based on weather conditions. Most healthy, well-watered vegetable crops at full growth will use about the same amount of water as the grass or alfalfa; taller crops or staked crops will use a little more. Earlier in the season, when vegetable plants are smaller, the water use will be less. Crop coefficients (Kc) have been developed to convert PET into expected evapotranspiration for specific crop (ETc). The crop coefficients take into account the specific crop and the stage of growth.

Reference evapotranspiration (PET) is available from the National Weather Service and the Indiana State Climate Office. These two articles describe how to find the relevant information: *Reference Evapotranspiration forecasts across Indiana*, *Monitoring potential evapotranspiration across Indiana*. For a detailed explanation of the evapotranspiration method and suggested crop coefficients (Kc) for vegetable crops, refer to *Crop evapotranspiration – Guidelines for computing crop water requirements - FAO irrigation and drainage paper 56*.

may occur deeper in the soil; above-ground symptoms may not appear until several days after the stress; and various pathogens may be isolated from the damaged roots and plant stems, complicating diagnosis.

The *Indiana High Tunnel Handbook* provides suggestions for improving drainage when constructing a high tunnel, and the article '*Water Drainage at High Tunnel Improved*' by Missouri State University provides an example of installing drainage tiles along the sides of a high tunnel. Additionally, growing crops on raised beds may prevent waterlogging from occurring in the part of the soil where the majority of the roots are located.

Managing Irrigation

During periods without rainfall, irrigation is crucial to ensure acceptable crop production. Consider the following factors for successful and effective irrigation management.

- Plant water needs
- Soil water-holding capacity
- Root structures
- Irrigation system capability

Plant Water Needs

During the peak of summer, most full-grown vegetable crops use 1 to 1.5 inches of water per week (*Sidebar 2: Estimating Plant Water Needs*), which equates to approximately 27,000 to 40,500 gallons per acre. For crops grown on a 3-foot-wide by 50-foot-long bed, this translates to about 100 gallons of water per bed per week during the summer. In a 30-foot by 96-foot-high tunnel, it requires about 1,500 to 2,500 gallons of water weekly. Although this may seem like a large amount of water, a significant portion of the water often comes from precipitation or soil moisture accumulated from heavy rains, either during the growing season or before planting in open-field production systems in Indiana.

Soil Water-Holding Capacity

Effective irrigation planning requires a comprehensive understanding of moisture content in the soil. If this is not fully considered, there is a risk of overwatering. Conversely, the risk of underwatering is equally critical. Soils that hold less water can quickly dry out without additional rainfall or irrigation. Typically, heavier soils retain more water than lighter ones, but organic matter content, soil structure, and other characteristics also play crucial roles in determining how much water the soil can supply after a heavy rain or through irrigation event (*Sidebar 3: Soil Water Relationships and Total Available Water for Soils of Different Textures*).

On a larger production scale, the USDA's Natural Resources Conservation Service offers the *Web Soil Survey*, a tool that provides detailed information about soils across the state, including the available water capacity of specific soils. However, this tool may be less practical for small-scale farmers, particularly in urban areas where construction may have significantly altered topsoil characteristics, or where soils have been heavily amended with organic materials, altering their water-holding capacity. In such cases, laboratory analysis is needed to accurately determine the soil's water-holding capacity. For most small-scale farmers, however, general knowledge and experience are usually sufficient for irrigation management. Soil moisture sensors, which are discussed in detail in Chapter 3, offer additional support for fine-turning irrigation practices.

Root Structures

Root condition profoundly impacts crop yield, health, and resilience to environmental stresses. However, due to their underground nature, root status is easily overlooked. While the general root structures of specific crops are genetically determined (*Sidebar 4: Root Structures of Tomato and Watermelon*), cultural practices including water management can significantly influence root growth, which in turn affects crops' irrigation needs.

When ample water is available in the topsoil, roots are generally less likely to penetrate deeper into the soil (Figure 18). Similarly, when soil conditions are dry and irrigation only wets a small area, roots tend to remain within the moist zone, avoiding drier regions. In both cases, the irrigation management practices limit root expansion. Similarly, when plants are grown in pots with soilless medium, the root volume is confined by the size of pot (Figure 19).

Limited root growth does not mean lower yields. In fact, excellent yields can be achieved in soilless systems where roots are restricted to a small volume. Maximizing yields in these systems requires intensive crop management, including frequent irrigation – sometimes as often as every few minutes – combined with fertigation to consistently supply water and nutrients to the small roots. However, given the limited root system in these systems, even a brief disruption in water and nutrient supply can lead to significant yield loss.

Conversely, when crops are grown in soil without physical barriers to root expansion and are exposed

Figure 18. *The cucumber plant roots accumulate near the emitters of the drip tape. The plants were grown in a high tunnel, where water was frequently supplied through drip irrigation.*

Figure 19. *The tomato plants are grown in 3-gallon bags with soilless medium.*

Sidebar 3. *Soil Water Relationships and Total Available Water for Soils of Different Textures*

Concepts of soil water relationships

Saturation: all the empty space between soil particles is filled with water. Plants may suffer waterlogging stress due to the lack of oxygen.

Field capacity: water in large pores has drained by gravity. Field capacity is the optimal soil moisture status for plant growth.

Permanent wilting point: the remaining water is held so tightly to soil particles that plants can no longer extract water from the soil.

Total available water: the amount of water available for plants to take up, which is the difference between soil water content at field capacity and permanent wilting point.

The information is adapted from Irrigation of field crops in Indiana: a guide for evaluating irrigation potential on your farm, 1977. ID-119, Purdue Extension

* Soil testing laboratories often offer services to assess soil texture. Additionally, the Soil Texture Calculator developed by NRCS provides a tool for farmers who want to perform this calculation by themselves.

Total available water for soils of different textures in Indiana

Soil Texture*	Inches per foot soil
Sand	0.6
Sandy loam	1.3
Loam	1.8
Silt loam	2.2
Clay loam	1.9
Clay	1.8

Sidebar 4: *Root Structures of Tomato and Watermelon*

The root structures of common vegetable crops grown in a natural environment reveal fascinating patterns and adaptations. The descriptions and root illustrations are adapted from "*Root Development of Vegetable Crops*" 1927, by John E. Weaver and William E. Bruner, McGraw-Hill Book Company, Inc.

Tomato

A tomato plant's roots can occupy soil up to 2 to 2.5 feet on all sides of the plant and extend to a depth of up to 3 feet. Generally, they have numerous and profusely branched lateral roots growing from the base of the stem. These lateral roots may extend horizontally outward or vertically downward. Mid-season, when the plants are actively blooming, the root system occupies soil approximately 1.5 feet around the plant and reaches a depth of 1 foot. In mature plants, the roots spread up to 2.5 feet on all sides and penetrate 2 to 3 feet deep into the soil.

Cucurbit plants

Unique to cucurbit plants of all kinds, their root growth spreads widely in relatively shallow soil. In early development, a few but very strong lateral roots grow horizontally within the top foot of soil, often exceeding the spread of the vines above ground. Most transplanted cucurbit plants lack a taproot so that the main laterals are grown near soil surface. Even for directly seeded plants, when a strong taproot can extend beyond 3 feet deep, the main lateral roots still occur within the top foot of soil and spread as wide as the vines. These lateral roots have numerous branches growing in all directions, forming an extensive root system that can occupy mostly surface soil areas up to 30 feet in diameter.

Root structure of a tomato (left) and a watermelon (right) plant.

throughout the season to cycles of soil moisture from full saturation to gradual dry down, crops like tomatoes can develop extensive root systems. These large root systems are better equipped to handle environmental fluctuations, such as drought or excess moisture, and can access a broader range of stored soil water and nutrients later in the season. Under these conditions, crops often thrive with less need for intensive inputs.

Considerations for Irrigation Frequency

We've discussed that irrigation frequency should take root status into account. But when should intensive root zone management be prioritized, and when should extensive root growth be encouraged? When high-value crops like tomatoes and cucumbers are grown in high tunnels or greenhouses, frequent irrigation that maintains soil moisture at field capacity is often preferred. This approach typically results in earlier harvests, higher yields, and consistent fruit quality, ensuring high economic returns. Depending on soil type, irrigation may be applied once or multiple times a day.

Conversely, when tomatoes, peppers, and melons are grown in open-field under natural environmental conditions with limited resources, irrigating only when the soil dries out may be more beneficial. While this method may not always result in maximized yields, the moderate water stress generally encourages deeper root growth, improving the plants' resilience to environmental stresses and enabling them to thrive with minimal intervention. Methods for determining soil moisture status are discussed in Chapter 3.

Other factors also influence irrigation frequency decisions. For crops grown in well-drained sandy soils, frequent irrigations that apply smaller quantities of water are advisable. This will reduce nutrient leaching by avoiding large applications that would be necessary if applied less frequently. In addition, sandy soils often require frequent irrigation because they don't hold enough water for longer periods. In contrast, in a soil with a larger water holding capacity less frequent irrigation would make sense. Less frequent irrigation may also be more effective in soils that are poorly

Figure 20. Different types of timers are used to control automatic irrigation systems on small farms.

drained, or in those with low permeability in which water does not move through the soil quickly. In these soils less frequent irrigation will reduce the risks of waterlogging due to unanticipated and excessive rainfall and the associated plant stress. Because these soils often retain a significant amount of water, plants are less prone to drought even with less frequent irrigation.

On small farms, irrigation frequency is often constrained by system capabilities. Without an automated system, applying irrigation more than once per day may not be practical. When frequent irrigation is necessary, many farms use automatic systems controlled by timers connected to the water source (Figure 20). These systems significantly reduce labor for irrigation management. However, most timers require regular monitoring and maintenance to ensure proper operation. Irrigation schedules controlled by timers should be promptly adjusted to account for rainfall, optimizing water use and preventing over-application.

Chapter 3. Estimating Soil Moisture Status

Feel-and-Appearance Method

As discussed in Chapter 2, effective irrigation planning requires a thorough understanding of soil moisture conditions. The feel-and-appearance method is a widely used approach for assessing soil moisture. The article "*Estimating Soil Moisture by Feel and Appearance*" provides detailed explanations of this method for different soil types. This method typically offers insights into the soil moisture status of the top 2 to 4 inches. When used with a soil probe, it can be extended to evaluate soil moisture levels at depths of 8 to 10 inches.

For shallow-rooted crops, such as leafy greens, the feel-and-appearance method is generally sufficient for managing irrigation. However, for deep-rooted crops like tomatoes, it is important to assess moisture in deeper soil layers. This can be difficult using the feel-and-appearance method, especially when the surface soil is dry (Figure 21). In such cases, soil moisture sensors provide a valuable tool for assessing soil moisture status at greater depths.

Soil Moisture Sensors

A variety of soil moisture sensors are commercially available, offering a wide range of prices, sensitivities, accuracies, and capabilities for estimating soil moisture levels of different soil depths and volumes.

Soil moisture sensors can be broadly classified into two main groups. One group measures or estimates the volumetric water content (VWC) of the soil, expressed as a percentage or in cubic meters of water per cubic meter of soil (m^3/m^3). The second group measures soil tension, which is the force required by plant roots to extract water from the soil, expressed in centibars (cbar). Each type of soil moisture sensor has its own advantages and limitations. For a detailed explanation of the sensors and how to install the sensors, refer to "*Improving Irrigation Water Use Efficiency: Using Soil Moisture Sensors*" by Michigan State University Extension.

***Figure 21.** Using a soil probe to excavate soils for estimating moisture content. The soil moisture levels shown in the images represent conditions at approximately field capacity (left), permanent wilting point (right), and an intermediate state (middle) of a sandy loam soil. Note: It was significantly easier to penetrate the soil profile when the soil was wet (left) compared to when it was dry (right).*

Tensiometers, a type of soil water tension sensor, provide an affordable option for assessing soil moisture. These devices provide readings that directly reflect the water stress experienced by plant roots, making them easy to interpret. Tensiometers have various tube lengths, with the most common being 6 inches, 12 inches and 18 inches, used to measure soil moisture

at corresponding depths (Figure 22). However, tensiometers require frequent maintenance, especially in dry conditions, respond slowly to changes in soil moisture, and often require manual reading and data collection.

Sensors that measure volumetric water content (Figure 23) respond quickly to changes in soil moisture. While some models require manual readings, most modern sensors automatically record data using integrated loggers, such as the Onset Hobo® MX2306, or connect with separate data loggers like the METER TEROS 12, which enable remote data access. However, these sensors are generally more expensive than tensiometers. Some models incorporate multiple individual sensors to measure soil moisture content at various depths, but this significantly increases the cost of the sensors.

Multiple Ways of Using Soil Moisture Sensors

Irrigation management involves decisions about when, how long, and how often to irrigate. While soil moisture sensors can be valuable tools, they are not a one-size-fits-all solution that will automatically provide these answers after installation. Instead, it is essential to have a plan that identifies the key questions in the irrigation decision-making process, and to strategically select the appropriate sensor types, and install them at the targeted location. Below are three ways we have found soil moisture sensors particularly helpful in guiding irrigation decisions.

1. Using soil moisture sensors to guide when to irrigate

We often use tensiometers for this purpose and find them helpful. The tensiometers measure soil water tension, which is close to zero when the soil is saturated, indicating that no irrigation is necessary. At field capacity the tensiometer may read from 5 to 40 centibars (cbar), depending on soil texture (Table 2). As the tension reading increases, it signals that the soil is beginning to dry out. At this point, we consider weather conditions, crop growth stages, and the specific soil depth being monitored to decide whether immediate irrigation is needed.

Unlike tensiometers, sensors that measure VWC have high values when the soil is wet. As the soil dries, the VWC value decreases, in contrast to the increasing tension readings of tensiometers as soil dries. If water is applied to already saturated soil, the VWC reading will spike before gradually decreasing as the soil approaches field capacity. This is different to tensiometers, which remain around zero in saturated soil. Some experience is required to interpret the VWC readings and changing

Figure 22. *Installing a tensiometer in the soil.*

Figure 23. *Sensors measuring volumetric water content were placed at different soil depths. The photo was adapted from Dong, Y. (2023). "Irrigation Scheduling Methods: Overview and Recent Advances."*

trends in order to determine whether the soil is merely draining or actually drying out. Therefore, when using VWC sensors to decide when to irrigate, it's crucial to accurately determine the VWC readings at field capacity for the specific soil and to initiate irrigation only if the sensor reading is below field capacity. The practical method to determine VWC readings at field capacity can be found in "*Principles and Practices of Irrigation Management for Vegetables*" by the University of Florida, IFAS Extension.

In precise irrigation management, an irrigation threshold is established based on the allowable percentage of available water depletion. Irrigation is initiated when this threshold is reached. Table 2 shows tensiometer readings that correspond to 20-25% depletion of available water for different soil textures. For drought-sensitive crops or those in critical growth stages, irrigation should begin when water depletion reaches or approaches 20-25% at the soil depth where the majority of roots are located. This means tensiometer readings

for the corresponding soil textures should be maintained at or below the values listed in the table for 20-25% depletion.

When using sensors measuring VWC, farmers may find it challenging to adopt precise irrigation management practices based on a threshold. This difficulty arises partly because converting the water depletion threshold into specific sensor readings requires accurate estimations of the sensor readings at both field capacity and the soil's permanent wilting point (*Sidebar 5: Formula for calculating percent water depletion and converting percent soil water depletion to sensor volumetric water content*). Estimating these values involves tracking soil moisture changes from full saturation to the permanent wilting point – a complex task, especially if sensors are installed for only part of the growing season.

Table 2. *Soil tension values for different soil textures for use in scheduling irrigation*

Soil Texture	Field Capacity	20-25% Depletion of Total Available Water
	Soil Tension Values (in centibars)	
Sand, loamy sand	5-10	17-22
Sandy loam	10-20	22-27
Loam, silt loam	15-25	25-30
Clay loam, clay	20-40	35-45

This table is adapted from the Midwest Vegetable Production Guide (mwvguide.org)

Regardless of the sensor type, precise irrigation management is more effective when soil moisture sensors are integrated with automated irrigation systems that trigger irrigation as soon as the threshold is reached. While implementing the automated systems is possible for small-scale farms, farmers need to weigh both the costs and maintenance of the automated system in the decision-making process.

2. Using soil moisture sensors to fine-tune an irrigation schedule

Both types of soil moisture sensors are suitable for fine-tuning a preset irrigation schedule controlled by a timer. Small farmers may use this system to grow high-value crops, such as tomatoes and cucumbers, in a high tunnel or greenhouse. Irrigation may be scheduled multiple times a day, depending on crop stage. Sensors are usually installed at a depth of 10-12 inches beneath the plants, considering most root activity occurs within the top foot of soil in frequently irrigated crops.

Sidebar 5: *Formula for calculating percent water depletion and converting percent soil water depletion to sensor volumetric water content.*

- Percent Water Depletion = [1- (Sensor VWC-PWP)/(FC-PWP)]*100
- Sensor VWC = FC – [(SWD*(FC-PWP)/100]
- VWC: Volumetric Water Content (m^3/m^3)
  PWP: VWC at permanent wilting point (m^3/m^3)
- FC: VWC at field capacity (m^3/m^3)
- SWD: Soil water depletion (%)

The soil is often well-watered at the start of the season. An initial irrigation schedule is established to maintain optimal soil moisture for young plants. As the plants grow, the sensors may detect a declining trend in soil moisture content or an increasing trend in soil tension, indicating that the current irrigation schedule is not meeting the plants' increasing water demands. In response, the irrigation duration or frequency may be increased to stabilize and maintain consistent soil moisture levels. When the volume is increased, it is important to avoid over-irrigation that wets soil beyond the root zone. (That will be discussed in the next section.) If soil moisture content continues to decrease, further adjustments to the irrigation amount may be necessary.

Typically, as plant growth slows down and begins to decline later in the season, plant water needs decrease. In such cases, sensors may show a general trend of gradual rise in soil moisture, signaling the need to reduce the irrigation amount. It is important to note that, when the soil is close to field capacity, tensiometers cannot detect soil saturation. Sensors measuring VWC are more helpful in detecting possible excess water application.

Table 3. *Estimated effective rooting depth of common vegetable crops.*

Shallow (6-12 inches)	Moderate (18-24 inches)	Deep (> 36 inches)
Beet	Cabbage, Brussels sprouts	Asparagus
Broccoli	Cantaloupe	Lima bean
Carrot	Cucumber	Pumpkin
Cauliflower	Eggplant	Sweet potato
Celery	Pea	Watermelon
Greens & herbs	Potato	Squash, winter
Onion	Snap bean	
Pepper	Squash, summer	
Radish	Sweet corn	
Spinach	Tomato	

We find this approach is most beneficial for farmers with prior experience in managing irrigation within the targeted cropping system. Incorporating the soil moisture sensors allows them to fine-tune their irrigation practices, adapting to each season's specific environmental and crop conditions.

3. Using soil moisture sensors to prevent over-irrigation at a single event

When using drip irrigation, it's easy to over-irrigate during a single event, especially when crops require large amounts of water to recover from a drought stress. Over-irrigation in one irrigation event can cause water to drain beyond the root zone, which not only wastes water and nutrients but also raises environmental concerns. While it is possible to calculate the maximum irrigation duration based on the soil's water-holding capacity, these calculations can be complex and rely on multiple assumptions that may not always be accurate for specific conditions.

A more reliable method for optimizing irrigation duration is by using soil moisture sensors. To do this effectively, soil moisture status should be monitored beneath the emitter and at relatively shallow depths that respond to each irrigation event. Additionally, a separate sensor should be installed below or at bottom of the root zone. The estimated rooting depth of common crops is listed in Table 3.

The moisture sensor placed nearer the surface should respond to each irrigation event, confirming that irrigation is functioning properly. Meanwhile, soil moisture monitored by the deeper sensor should remain stable. If soil moisture at the bottom of the root zone increases after an irrigation event, it indicates that the irrigation duration is too long. In such cases, the irrigation volume should be reduced or the time between irrigations should increase.

Chapter 4. Irrigation Methods and Systems

Low-flow overhead and drip irrigation are the two most commonly used irrigation systems on small farms in Indiana. On farms growing a diverse range of crops, both systems are often utilized to meet the specific needs of each crop, and sometimes for the same crop at different stages of growth.

Low-Flow Overhead Irrigation

Most small farms opt to set up low-flow overhead systems, either hanging inside high tunnels (Figure 24) or using portable setups on the ground in both high tunnel and open-field condition (Figure 25). Low-flow overhead irrigation is commonly used for directly seeded cash crops, such as salad greens, spinach, carrots, and beets. It is also applied to cover crops and high-density plantings.

The low-flow overhead irrigation system typically involves multiple micro-sprinklers or wobblers installed on a quarter-inch feeder tube attached to a water supply line. The coverage areas and water volume can be adjusted by selecting different emitters, spacing them at various distances along the header line, and modifying their height from the ground. Many irrigation supply companies offer services to help farmers design customized systems and select emitters based on the designed coverage area.

Achieving uniform water application is essential for effective overhead irrigation. A non-uniform system

Figure 24. *A micro-sprinkler irrigation system hanging on the roof of a tunnel.*

Figure 25. *A micro-sprinkler system, positioned along the length of the bed and placed on the ground, is used to irrigate directly seeded and high-density crops.*

can lead to areas being under- or over-irrigated, complicating management and risking crop loss. To assess irrigation uniformity, place rain gauges or containers across the entire target area (Figure 26). After irrigating for a set period, measure the water collected at each location. It's recommended to evaluate uniformity after installing a new irrigation system and to conduct regular checks, as sprinklers or wobblers may become clogged, and system pressure can fluctuate over time.

A well-designed overhead irrigation system wets the entire planting area, ensuring even seed germination and eliminating the need for multiple drip tapes on the beds. In the summer, overhead irrigation may also help lower the temperature for cool-season crops.

Overhead irrigation has drawbacks: It encourages weed growth, is less water-efficient, and can create wet canopies that favor foliar diseases. Due to these pros and cons, for directly seeded high-value crops grown in high tunnels, farmers may use both overhead and drip irrigation methods for the same crop but at different stages. Overhead irrigation is employed during seed germination, with a switch to drip irrigation once plants have developed 4 or 5 leaves (Figure 27).

Drip Irrigation

Drip irrigation delivers water directly to the soil, ensuring high water-use efficiency and avoiding water contact with leaves, which significantly reduces the risk of foliar diseases. Most farms utilize drip tapes, which are available in a variety of thicknesses, emitter spacings, and flow rates to accommodate different needs. Drip tape is specifically engineered for agricultural use and differs from the soaker hoses commonly available for home gardens.

If drip tape is intended for reuse, choosing more durable tapes with thicker walls is advisable. The choice of emitter spacing should align with the crop in-row spacing. For crops spaced 2 feet or more apart, a 12-inch emitter spacing is commonly used, while closely spaced crops benefit from emitter spacings of 4 to 8 inches. When installing drip tape, it is recommended to position the emitters facing upward to reduce the risk of clogging. Additionally, placing drip tape under mulch improves water use efficiency and protects it from direct sunlight, which can shorten its lifespan.

Since drip tapes can become clogged over time, which is often difficult to detect, some farmers prefer to use individual emitters and emitter tubing attached to a water supply line for high-value, widely spaced crops such as tomatoes (Figure 28). This system is effective and can be reused for multiple seasons, but it significantly increases the initial material cost.

Figure 26. *Multiple rain gauges are placed in the tunnel to assess irrigation uniformity.*

Figure 27. *Overhead and drip irrigation are both used in the caterpillar tunnel at different crop growth stage.*

Figure 28. *The individual emitter and emitter tube attached to the water supply line is used in growing tomatoes.*

One drawback of drip irrigation is that it wets only the soil directly beneath the emitters (Figure 29). Depending on soil type, the maximum wetted area may extend 1 to 1.5 feet in diameter before water drains deeper into the soil profile. Due to the limited wetting areas, it is advisable to use multiple drip tapes per bed when planting multiple rows of crops on a single bed (Figure 27). This approach also benefits wider-spaced crops, such as tomatoes, peppers, and cucumbers, in high tunnels (Figure 30). This is because using multiple drip tapes ensures that a larger soil area is wetted, encouraging crops to develop a more extensive root system. Additionally, maintaining proper soil moisture is crucial for sustaining microbial activity, which plays a key role in converting soil amendments and organic matter into available nutrients that support plant growth.

***Figure 29.** Drip irrigation wets the soil area directly beneath the emitters.*

Usually, two drip tapes per bed are recommended, though some farmers may use up to four. When additional drip tapes are added to the bed, irrigation timing should be adjusted accordingly.

Irrigation Systems and Principles in Designing Irrigation Zones

Irrigation system design varies based on water sources, system scale, and management practices. However, regardless of scale, every system should include key components such as drip tapes or sprinklers, header pipes, flow meters, pressure regulators, pressure gauges, filters, and backflow preventer if fertilizer or chemical are injected. Additionally, understanding flow rate is fundamental for irrigation system design.

***Figure 30.** Multiple drip tapes are used on one tomato bed.*

The first step in this process is to determine the flow rate available from water source. If this information is not provided by the water supplier, farmers can measure it by timing how long it takes to fill a 5-gallon (or larger) container and then calculating the flow rate in gallons per minute (gpm) or gallons per hour (gph).

Flow rate information for micro-sprinklers, individual emitters and drip tape is provided by the manufacturer, expressed in gph per emitter or gpm per 100 feet at a certain pressure, e.g., 8 pounds per square inch (psi). To determine the total flow rate of an irrigation system, sum the flow rates of individual outputs (sprinklers, emitters, and drip tapes). It is crucial to ensure that the system's total flow rate does not exceed the available flow rate from the water source. If it does, the system should be divided into separate zones, with each zone irrigated at different times.

Understanding flow rate is also important for effective irrigation management. For example, assume the goal is to apply 100 gallons of water through drip tape to one bed in a week. Farmers can calculate how long irrigation should run to deliver the required amount of water based on the drip tape flow rate.

Micro-sprinklers typically operate at a pressure range of 20 to 30 pounds per square inch (psi), while drip tapes are designed to function within a range of 8 to 15 psi. Operating the system within these optimal pressure ranges ensures the water is applied evenly and at the desired flow rate. It is important to note that water pressure decreases as it travels through the system.

The irrigation system will include a "mainline" pipe or hose to deliver water from the source to each irrigation zone. Each zone will have a "sub-main" or "header" that provides water to the drip or micro-sprinkler for that zone. A flow meter, a pressure regulator and a pressure gauge are often incorporated into each zone of the irrigation system. The pressure regulator and pressure gauge ensure the system runs at consistent and optimal pressure ranges. The flow meter monitors the actual volume of water being applied to the system to ensure expected amount of water is applied to the system.

Filters are important to prevent clogging in micro-sprinklers and drip irrigation. Screen filters with a 150 to 200 mesh screen or comparable disc filters are suitable for city water or ground water. Sand filters are necessary for surface water, and a sand separator might also be necessary. A thorough discussion of filters is available in "*Filtration, Treatment, and Maintenance Considerations for Micro-Irrigation Systems*" from Virginia Tech. If acid, fertilizers, or pesticides will be injected into irrigation water, a backflow preventer between the injection point and water supply is necessary to prevent the material from contaminating the water source.

Detailed information about irrigation components can be found in specialized irrigation publications. "*Drip-irrigation Systems for Small Conventional Vegetable Farms and Organic Vegetable Farms*" by the University of Florida, IFAS Extension, offers an excellent overview of irrigation system designs and components.

Chapter 5. Irrigation Water Quality

Irrigation water quality can be evaluated based on its chemical, biological, and physical properties. It plays a critical role in vegetable production, influencing crop growth, soil conditions, equipment performance, and, in some situations, produce safety. Understanding these key water quality parameters and taking preventive measures, producers can avoid potential production issues.

Irrigation water quality should be assessed in the context of a given production system. This bulletin primarily addresses water quality for soil-based vegetable production. For hydroponic systems, where all plant nutrients are supplied through water, knowing the precise mineral content is crucial for determining any additional nutrients that need to be added. Hydroponic producers should follow guidelines specifically designed for these systems. This bulletin focuses on water quality parameters most likely to impact vegetable production on small farms in Indiana. Since most laboratories provide recommended ranges for each parameter in the reports, the desired ranges are not included in the bulletin.

Chemical Characteristics of Irrigation Water

The chemical characteristics of irrigation water encompass factors like pH, alkalinity, salinity, and the presence of specific minerals that can be of concern. Depending on water sources, attention should be placed on specific parameters.

pH and alkalinity

pH and alkalinity are related to irrigation water's acidity and basicity and potential impact on soil pH. pH is a measure of whether the water is acidic or basic. pH 7 is neutral, less than 7 is acidic, and greater than 7 is basic. pH of Indiana well water typically ranges between 6.5 to 8. High pH is common in groundwater in Indiana, which is usually associated with high alkalinity.

Alkalinity is the ability of water to neutralize acid. It is caused by bicarbonates, carbonates, and hydroxides dissolved in the water. Alkalinity is often reported as bicarbonate (HCO_3) in units of milligrams per liter (mg/l) or parts per million (ppm). For Indiana groundwater, alkalinity is closely related to water hardness. Both alkalinity and hardness are also reported as calcium carbonate ($CaCO_3$), in units of mg/l or ppm, or milliequivalents per liter (meq/l). Most Indiana groundwater is considered very hard. Localized areas of exceptionally hard water are found in northwestern Indiana in Lake County, south-central Indiana in Harrison and Washington counties, and northeastern Indiana in Adams County (Figure 31).

Although high pH and alkalinity are common issues in Indiana's groundwater, they are rarely a concern when surface water is used as the main water source for irrigation.

Problems caused by alkaline water

In open field production, high alkalinity in irrigation water can lead to problems such as emitter clogging and lime deposits on irrigation system components.

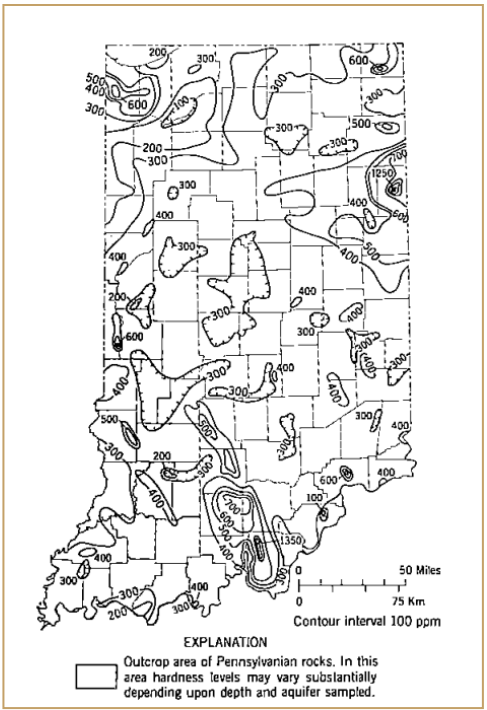

Figure 31. *Map of Indiana showing the distribution of water hardness of groundwater in parts per million (ppm) CaCO3. The map is adapted from Water Quality, Indiana Department of Natural Resources. https://www.in.gov/dnr/water/files/804_Water_Quality.pdf*

Figure 32. *Tomato yellow shoulder, a tomato fruit disorder typically occurs due to a deficiency in potassium, which might be caused by high levels of calcium and magnesium in the soil.*

In high tunnels, in addition to the lime deposits, the primary concern with alkaline irrigation water is the gradual increase in soil pH over time. This is because the alkalinity often results from dissolved calcium and/or magnesium carbonates, which are essentially dissolved lime. With each irrigation, a small amount of lime is added, accumulating over the season. For example, applying an inch of water per week for 15 weeks with water containing 450 ppm bicarbonate is equivalent to applying 85 lb. per acre per week of calcium carbonate lime, or more than half a ton per acre over the 15 weeks.

Sandy soils will experience pH increase more rapidly than heavier soils or soils with greater cation exchange capacity. Eventually, the soil pH can rise to a level where mineral nutrients become less available for plant uptake. Micronutrients such as manganese, iron, and zinc become less available at high pH levels, with manganese availability declining the most rapidly.

In addition to raising soil pH, using high-alkalinity water in covered structures over time may elevate soil levels of calcium and/or magnesium. While calcium and magnesium are essential plant nutrients, excessive levels can interfere with the uptake of potassium. Tomatoes require substantial amounts of potassium to produce high-quality fruit. If soil calcium and magnesium levels are excessively high relative to potassium, plants may not be able to absorb enough potassium, which increases the potential of developing yellow shoulder fruit (Figure 32).

Strategies for addressing alkaline water

For soil production in the open field, as natural rainfall contributes significantly to plant water needs, it is less likely that alkaline irrigation water would raise soil pH. However, if scale buildup or plugging is a problem, water may need to be acidified as discussed below.

In high tunnels, it is important to monitor soil pH annually and track changes over time to identify the trends. If irrigation water alkalinity is causing an increase in soil pH, consider using an alternative water source with lower alkalinity or mixing it with the less alkaline water. Surface water from ponds, streams, or rainwater collected in tanks generally has low alkalinity.

If needed, high alkalinity water can be treated by injecting acids such as sulfuric, phosphoric, or nitric acid. A calculator to determine the appropriate amount of acid to use can be found at *https://alkcalc.egromobi.com/*. For more detailed guidance, the article "*Adjusting alkalinity with acids*" by University of Massachusetts Extension provides comprehensive information on acid use for irrigation water. It is essential to use the correct amount of acid to avoid excessively lowering the pH, which can lead to other issues. Additionally, concentrated acids are hazardous, so proper safety precautions must be followed. In organic production, some farmers may choose to use citric acid, though its effectiveness and economic feasibility have not been fully tested.

Acid injection can also be used intermittently to prevent clogging and carbonate precipitation. For this purpose, it is recommended to inject enough acid to lower the

water pH below 4, then run the water for 30 minutes to an hour. Other water treatments, such as reverse osmosis, and potassium-based water softeners, can also be used to reduce alkalinity and lower pH. However, the cost-effectiveness of these systems has not been fully evaluated in soil production.

Most vegetable crops thrive in slightly acid soil with pH range of 6.0 to 6.5. If soil pH rises above 7, amendments such as elemental sulfur, and ammonium-based fertilizers can be used to lower it. For more detailed information on adjusting soil pH, refer to article "*Lowering Soil pH for Horticulture Crops*" by Purdue Extension.

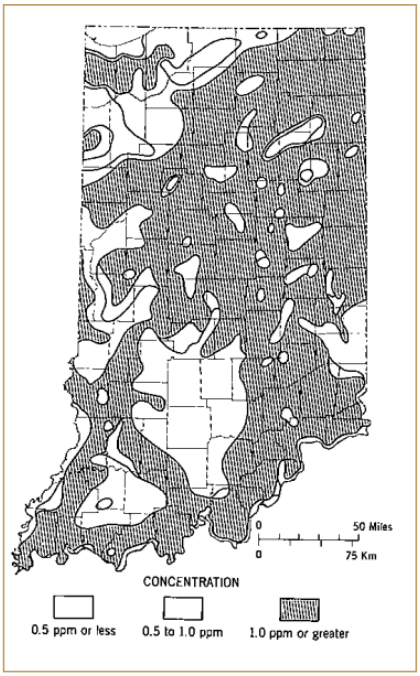

Figure 34. *Map of Indiana showing the general concentration of iron in ground water (ppm). The map is adapted from Water Quality, Indiana Department of Natural Resources. https://www.in.gov/dnr/water/files/804_Water_Quality.pdf*

Other chemical parameters

Iron – Groundwater in Indiana commonly has higher iron concentrations than the recommended maximum of 0.3 ppm (Figure 34). In aquifers, iron is in the ferrous form, dissolved in the water. When the water is brought to the surface and through an irrigation system, the pH and oxygen levels in the water increase, causing the iron to change to the insoluble ferric form. It forms orange or reddish precipitates that can plug emitters and look like a coat of rust on areas wet by the water (Figure 35). It can also promote growth of iron bacteria, which create slime and additional plugging.

To prevent plugging, a common strategy is to force the iron into the insoluble form and remove the precipitate

Figure 35. *Iron deposit on drip tape.*

before it reaches the emitters. It is also possible to use softeners to remove iron in water. Refer to article "*Management of iron in irrigation water*" by Rutgers Cooperative Research & Extension.

Salinity – Salinity refers to the total concentration of dissolved salts in water, typically measured using electrical conductivity in units of deci-Siemens per meter (dS/m) or millimhos per centimeter (mmho/cm). High soil salinity levels can negatively affect crop growth, but this issue usually stems from salt accumulation due to fertilizers or certain soil amendments. In Indiana, high salinity in irrigation water is rarely a concern.

Sodium – Sodium contributes to salinity and is reported in units of mg/l or ppm. While high sodium levels in untreated well water are uncommon in Indiana, it can still occur. Some aquifers naturally contain elevated sodium levels, and sodium can also enter wells through contamination from road salts or other sources. Common water softeners remove calcium and magnesium and replace them with sodium. It is not recommended to use sodium-softened water for irrigation.

Boron – Boron is a micronutrient essential for plant growth in very small quantities. However, excessive boron is toxic, and the range between sufficient and harmful amounts is narrow. Although high boron levels in well water are uncommon in Indiana, its presence should be monitored.

Chloride – Chloride levels are generally low in natural water sources in Indiana, but treated water may have higher concentrations. Chloride concentrations above 300 ppm are toxic to sensitive crops when absorbed through the roots. Additionally, overhead irrigation water with chloride levels above 175 ppm can cause toxicity in tomato leaves.

Manganese – Manganese levels in Indiana wells can exceed recommended levels. The primary concern for irrigation is that manganese can form a black precipitate, which may clog irrigation systems. However, manganese precipitates much more slowly than iron, making it less of an issue in irrigation water.

Sulfate – Sulfate concentrations can be high in Indiana well water, causing unpleasant taste and odor. However,

since sulfur is an essential plant nutrient, its presence in irrigation water is not problematic. Instead, sulfur from irrigation water can be factored into nutrient management plan.

Nitrate-nitrogen – Nitrate-nitrogen is often measured in irrigation water, with high concentrations typically indicating contamination from fertilizer runoff, leaching, sewage, or manure storage. Concentrations above 10 ppm in drinking water pose significant health risks. However, since nitrogen is a key plant nutrient, nitrate-nitrogen in irrigation water is not a problem for plant growth. High levels can be incorporated into the overall nutrient management plans.

Biological Characteristics of Irrigation Water

Biological concerns include microbes — bacteria, fungi and others — and algae. Slime-producing iron bacteria were discussed above. There are similar sulfur bacteria that produce a white slime and can also be managed with chlorine.

Plant pathogens can occasionally be found in surface water. Pythium and phytophthora are two fungi like organisms — water molds — with spores adapted to moving around in water. Phytophthora has been found in surface waters, such as streams. The spores move with runoff from a field into retention ponds and streams, which may later be used for irrigation, moving the pathogen to another field. Plant diagnostic labs don't routinely test irrigation water for plant pathogens, but they can help diagnose disease problems when you suspect a link to irrigation water quality. For help, contact *Purdue Plant and Pest Diagnostic Lab*.

Human pathogens in irrigation water are a food safety concern. Good Agricultural Practices (GAPs) for food safety include guidelines for assessing and reducing risk in irrigation systems, water sources, and irrigation practices. Producers covered under the federal Produce Safety Rule (PSR) of the Food Safety Modernization Act (FSMA) are required to assess agricultural water for potential contamination risks at least annually, which can include testing irrigation water for generic *E. coli*. In addition, growers should assess the entire irrigation system for risk and implement corrective actions if necessary. It is recommended that all producers of fresh produce follow these guidelines. Producers who are required by their buyers to pass a third-party GAPs audit will likely need to test water as part of their food safety protocol. Learn more at *Safe Produce Indiana*, including how to determine if you are covered under the PSR.

A key approach to dealing with human pathogenic bacteria is to, when possible, understand relative risk of various practices, choose less risky practices, and use best practices to mitigate those risks. The source of the water is an important factor in risk. Municipal and other public water systems maintain water at standards for drinking and so are at very low risk for contamination with human pathogens. Private wells have a medium risk because they can become contaminated from septic systems, wildlife, or manure if not maintained properly, and are not tested as frequently. Ponds, streams, rivers and other surface water carry the most risk, as they are the most likely to contain pathogens.

The method of water application also influences risk of contaminating produce. Practices that allow irrigation water to contact the edible part of the crop are the riskiest: sprinkler irrigation of tomatoes, or for root crops, any irrigation that wets the soil around the edible root. Drip irrigation with the drip tape placed underneath a mulch or buried in the soil would have a low risk for a tomato crop.

Physical Characteristics of Irrigation Water

Water sediments

Irrigation water from a pond, stream, or cistern may contain algae or sediment that can plug or damage equipment. Algaecides containing chlorine or copper sulfate can be used in some situations. Filters are critical for catching sediment. Sand filters are commonly used for this purpose. A pair of containers filled with sand catches the sediment. Periodically the filters must be back-flushed. Sand filters are available from irrigation supply companies, or can be made on the farm as described in the publication "*Low-Cost Irrigation Sand Filter*" by the University of Vermont Extension.

Water temperatures

The temperature of irrigation water can significantly impact seed germination and plant growth. During the summer, using cooler water may enhance the germination of heat-sensitive seeds such as spinach and lettuce. Surface water may not be cool enough to make a significant difference, so if groundwater is readily available, that would be a better choice for cooling the soil. In later fall, winter and spring, when soil temperatures are low, irrigation with warm water can help raise soil temperatures, promoting faster plant growth. This is especially beneficial for warm-season crops, such as cucumbers, grown in the spring.

Irrigation Water Tests

Chemistry tests

Municipal and public water supplies are required to test water regularly and provide results to users. Contact a water department to request the results. The standard

report mailed to customers may not include information on all of the chemistry discussed above.

Several commercial laboratories offer testing services for private well water or surface water to assess irrigation suitability. The followings are examples. This is not an all-inclusive list.

- *A&L Great Lakes*
- *Brookside Labs*
- *Waters Ag Labs*

In addition to a comprehensive irrigation water suitability test by a commercial lab, on-farm tools are available for testing pH, electrical conductivity (EC), alkalinity (or hardness), and nitrate-nitrogen. The least expensive are color-based systems, such as litmus paper for pH, or alkalinity or nitrate test strips. While these methods are less precise, they offer quick and easy results.

For growers who frequently mix soluble fertilizer, inject acid into irrigation system, or regularly monitor growing medium pH or electrical conductivity, having a reliable pH and EC meter is extremely useful. These meters can also be used to test irrigation water. New technologies that integrate with smartphones are likely to become available, offering even more convenient and capable testing options.

Biological tests

Testing water for food safety purposes involves testing for the indicator bacteria generic *E. coli*. If generic *E. coli* is present, it is likely that the water has been contaminated with fecal matter, and human pathogens are more likely to be present. If indicator bacteria are present in high numbers the water must be treated before use, or applied in a way that it will not contact the edible portion of produce normally eaten raw.

Refer to the publication "*Indiana Water Testing Labs*" by Safe Produce Indiana for a complete list of labs that perform the test for generic *E. coli.* If you wish to use the water source for drinking, hand-washing or washing produce as well as irrigation, a presence/absence test is adequate because zero detectable *E. coli* is permitted in water used for those purposes. If you need to use the water source only for irrigation, choose a lab that offers quantification. Be sure to follow closely the instructions the lab will send for collecting the sample and sending it in for testing.

Frequency of irrigation water testing

The chemistry of well water can change over time. An annual test before the irrigation season would allow timely actions before the season starts. If annual tests show little to no variation, it may be reasonable to extend the time between tests, provided there are no changes (e.g., droughts or increased aquifer usage) that could impact water quality. For food safety purposes, it is highly recommended that water testing be conducted at least annually if the grower is held to no other regulatory or buyer-driven requirements. Be sure to consult specific food safety regulations for detailed water testing requirements.

For more information on irrigation water quality, the *Clean Water*[3] website offers a wealth of resources covering this topic.

Chapter 6. Mulches and Water Management

Using mulch to maintain soil moisture is highly effective and widely adopted on small farms. In addition to conserving moisture, mulch plays a crucial role in controlling weeds and reducing soil erosion. Additionally, natural mulches contribute to soil fertility over time as they decompose.

While traditional vegetable farms often rely on plastic mulches, small farmers tend to use a variety of materials tailored to their specific needs and availability (Figure 36). These include synthetic options, such as plastic mulch and landscape fabric, as well as natural materials, such as straw, woodchips, compost, leaves and wool. Biodegradable materials, including paper, cardboard, and burlap bags, are also utilized on small farms.

Figure 36. *Various mulch materials are used at small farms.*

For a comprehensive overview of different types of mulches, their applications, and their effects on soil health, refer to the "'*Mulches for Small Farms and Gardens Overview*" by NRCS. This bulletin mainly focuses on the relationships between common mulches and water management.

As mentioned earlier, plants with extensive root systems, like tomatoes and melons, often extend their roots beyond the planting beds. Applying mulch to both planting beds and pathways helps retain soil moisture over a larger area, supporting root expansion and benefiting soil microorganisms, which enhances overall soil health. The effectiveness of mulch in retaining soil moisture, influencing soil temperature, and impacting soil health depends on the type used.

Black plastic mulch raises soil temperatures, making it particularly useful in the spring for growing warm-season crops. In contrast, white plastic mulch cools soil, making it beneficial for crops transplanted after the soil has warmed. Farmers may use white plastic instead of black plastic for summer-planted tomato and pepper to prevent heat damage to young seedlings, particularly around the planting holes.

Plastic mulch is impermeable to water, and when combined with drip irrigation it significantly enhances irrigation efficiency. However, when plastic mulch is used with overhead irrigation or relies primarily on natural precipitation, the soil beneath it can become drier than adjacent areas. This is because roots absorb the moisture, and the plastic blocks water from reaching the soil underneath the plastic. Soil in the bed will get water only after heavier rain or irrigation leads to water infiltration into the bed from the sides and from the water that enters the planting holes. While drier conditions under plastic mulch can be advantageous in excessively wet situations, they negatively impact crops when irrigation and rainfall are limited. A drawback of using plastic mulch is the lack of options for reuse or recycling if it is not biodegradable.

Compost made from leaves and other plant materials, or food wastes, is often applied as a mulch on top of the soil. Typically, a 2-inch layer of compost is used, which effectively suppresses weeds and significantly improves soil fertility. Some farmers may plant seeds directly into the compost mulch. However, as the dark color of the compost can cause the surface to dry quickly, special attention must be given to maintaining adequate moisture for seed germination. Additionally, if the compost hasn't been thoroughly watered, it may have high salts, which can inhibit seed germination. Compost made from plant- or animal-based materials can lead to excessive phosphorus buildup in the soil, potentially causing nutrient imbalances. Regular soil tests should be conducted to monitor these changes.

Woodchips are highly effective at maintaining soil moisture, and when applied 3-4 inches deep, they often provide better weed control compared to straw mulch of the same depth. However, woodchips have drawbacks when used as mulch in vegetable planting rows. In excessively wet conditions, the soil beneath woodchips can become saturated for extended periods, which can hinder plant growth. If this saturation occurs early in the season, it can damage roots, making recovery difficult and potentially affecting growth and yield for the remainder of the season. As a result, woodchips are generally not recommended for vegetable planting beds in open fields exposed to natural rainfall in Indiana, though they are an excellent choice for pathways. Additionally, when mulch materials with high carbon content are incorporated into the soil, additional nitrogen needs to be applied to support immediate crop production.

When using organic mulch with transplanted plants, ensure the mulch does not come into direct contact with the plant stems. Direct contact can increase the risk of diseases occurred around the stem, which may lead to plant death.

Suggested Resources

Chapter 1

Midwest Vegetable Production Guide. https://mwveguide.org/guide

Chapter 2

Water Drainage at High Tunnel Improved. Missouri State University. https://blogs.missouristate.edu/fruitexperimentstation/2017/11/09/water-drainage-at-high-tunnel-improved/

Indiana High Tunnel Handbook. Purdue University Extension. https://www.extension.purdue.edu/extmedia/HO/HO-296.pdf

Web Soil Survey. USDA, NRCS. https://websoilsurvey.nrcs.usda.gov/app/HomePage.htm?TARGET_APP=Web_Soil_Survey_application_ffsdbb3dq5ewitkh0ko13l5w

Reference Evapotranspiration Forecasts Across Indiana. Vegetable Crops Hotline. https://vegcropshotline.org/article/reference-evapotranspiration-forecasts-across-indiana/

Monitoring Potential Evapotranspiration Across Indiana. Vegetable Crops Hotline. https://vegcropshotline.org/article/monitoring-potential-evapotranspiration-across-indiana/

Crop Evapotranspiration- Guidelines for Computing Crop Water Requirements – FAO Irrigation and Drainage paper 56. https://www.fao.org/4/x0490e/x0490e00.htm#Contents

Irrigation of Field Crops in Indiana. Purdue University Extension. https://earchives.lib.purdue.edu/digital/collection/AESmimeoID/id/1437/rec/115

Soil Texture Calculator. USDA, NRCS. https://www.nrcs.usda.gov/resources/education-and-teaching-materials/soil-texture-calculator

Root Development of Vegetable Crops. https://soilandhealth.org/wp-content/uploads/01aglibrary/010137veg.roots/010137toc.html

Chapter 3

Estimating Soil Moisture by Feel and Appearance. USDA, NRCS. https://www.wcc.nrcs.usda.gov/ftpref/wntsc/waterMgt/irrigation/EstimatingSoilMoisture.pdf

Improving Irrigation Water Use Efficiency: Using Soil Moisture Sensors. Michigan State University Extension. https://www.egr.msu.edu/bae/water/irrigation/sites/default/files/content/E3445_Improving%20Irrigation%20Water%20Use.pdf

Principles and Practices of Irrigation Management for Vegetables. University of Florida, IFAS Extension. https://edis.ifas.ufl.edu/publication/CV107

Chapter 4

Filtration, Treatment, and Maintenance Considerations for Micro-Irrigation Systems. Virginia Cooperative Extension. https://www.pubs.ext.vt.edu/442/442-757/442-757.html

Drip-Irrigation Systems for Small Conventional Vegetable Farms and Organic Vegetable Farms. University of Florida, IFAS Extension. https://edis.ifas.ufl.edu/publication/HS388

Chapter 5

Water Quality. Indiana Department of Natural Resources. https://www.in.gov/dnr/water/files/804_Water_Quality.pdf

ALKCALC. https://alkcalc.egromobi.com/

Adjusting Alkalinity with Acids. University of Massachusetts Extension. https://ag.umass.edu/greenhouse-floriculture/fact-sheets/adjusting-alkalinity-with-acids

Lowering Soil pH for Horticulture Crops. Purdue University Extension. https://www.extension.purdue.edu/extmedia/ho/ho-241-w.pdf

Management of Iron in Irrigation Water. Rutgers Cooperative Research & Extension. https://njaes.rutgers.edu/fs516/

Purdue Plant and Pest Diagnostic Lab. https://ag.purdue.edu/department/btny/ppdl/

Safe Produce Indiana. https://ag.purdue.edu/department/extension/safeproduce/

Low-Cost Irrigation Sand Filter. University of Vermont Extension. https://www.uvm.edu/sites/default/files/The-Center-for-Sustainable-Agriculture/resources/SandFilterHowToLarge.pdf

A&L Great Lakes Laboratories. https://algreatlakes.com/
Brookside Labs. https://www.blinc.com/

Waters Agricultural Laboratories. https://watersag.com/

Indiana Water Testing Labs. Safe Produce Indiana. https://ag.purdue.edu/department/extension/safeproduce/_docs/indiana-water-testing-lab-guide-6-9-2021.pdf

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Mulches for Small Farms and Gardens Overview. USDA, NRCS. https://static1.squarespace.com/static/601099353a53016c03aa44c5/t/66e1b87a2665cd471fc36c4d/1726068858987/484+IN+PO+Mulching+for+Small+Farms+and+Gardens+2024.pdf

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All photos except Figure 23 by Wenjing Guan and Elizabeth Maynard

22 WAYS TO OPTIMIZE HIGH TUNNEL PRODUCTION

Vern Grubinger, vegetable and berry specialist, University of Vermont Extension

High tunnel systems vary a lot – from super simple to all the bells and whistles – depending on grower goals, crops, finances, etc. so it's hard to make one list of improvements that fits everyone's situation. Maybe you've done all these things, or maybe you don't need to. Hopefully there's something in the list below that's helpful to your high tunnel management!

1. **Replace greenhouse plastic before it's too old**. Most greenhouse plastic is rated for 4 years of use. Although they may hold up longer than that physically, all plastic films lose light transmission capabilities over time. Even with UV stabilizers that slow degradation, dust, dirt, and air pollutant accumulation can reduce light available to crops for photosynthesis. Tests of UV-stabilized plastic covering on a multi-bay greenhouse revealed a 6.8% reduction in transmission in Photosynthetically Active Radiation (PAR) after 4 years. Using a PAR meter, or quantum sensor, I have observed this on farms myself. The difference in PAR transmission between old and new covers is more important to crop growth when sunlight is limited, as it is early in the season, or on cloudy days.

2. **Add ground post extensions** to increase height of short tunnels. Many older tunnels were shorter than the norm today, so they have small interior volumes and short sidewall openings that limit passive ventilation. When replacing plastic, consider adding sidewall extensions to raise the height of the structure, which will reduce temperature fluctuations by increasing the volume of air. This also improves ventilation and lowers humidity more when bigger sidewalls are fully open. Depending on tunnel design it can also allow for growing taller crops and make room for workers to stand up next to tunnel edges. Cross braces or other structural improvements may be needed to ensure tunnel stability after ground post extensions are added.

3. **Optimize roll up sides**. Back in the day, a piece of pipe was how most sidewall plastic was rolled up. Today, there are many easier, and safer methods available that use geared systems powered by hand or electricity. There are also automated systems that use sensors to raise and lower the sidewalls depending on environmental conditions. These are not inexpensive but growers I've talked to say they help optimize crop growing conditions by avoiding exposure to hot/cold temperatures when someone is not available to change the sidewall opening, and they offer some peace of mind if you're away from the farm when the weather changes significantly.

4. **Add drip lines if needed** to wet the entire root zone. The extent to which irrigation water moves sideways in soil after it is applied depends on capillary movement. Capillary movement is enhanced by clay and organic matter content of soil. So if your soil is on the sandy side then there may be large dry areas between your irrigation lines if they are widely spaced. That can limit root growth and prevent plants from taking up nutrients even though they were applied. Adding extra drip lines is a low-cost way to make sure that water is distributed uniformly across the entire tunnel growing area. Set up irrigation timers, even inexpensive ones can help provide a consistent water supply.

5. **Improve ventilation**: add a ridge vent or install hinged gable vents in endwalls. Good ventilation not only provides a consistent supply of fresh air and thus CO2 for plant growth, it's also critical to managing humidity which can shut down photosynthesis if it's too high, as well as promote foliar plant diseases. Ridge vents are very effective and promoting air flow and ventilation in high tunnels, though they are not inexpensive, and I hear growers complain about changing the plastic with them. A lower cost alternative, albeit with less impact on air flow, is to install large openings near the top of tunnel endwalls, or gable vents. These can be hinged to open inward, or in "butterfly" fashion. Outward openings are more susceptible to wind damage. Typically, rope and pulley systems are used to operate gable vents.

6. **Improve air circulation** with HAF fans. Air circulation is not the same as ventilation. Circulation mixes internal air, reducing gradients in temperature, humidity, and CO2 that may be present. Ventilation without circulation can lead to corners or other areas of a tunnel not having sufficient air exchange. Properly installed horizontal air flow fans are a good investment in many high tunnels. Small, 1/10 to 1/15 hp HAF fans with permanent split capacitor motors work well. They move more air yet use less electricity than cheap box fans with shaded pole motors that are often seen in high tunnels.

7. **Size ventilation and circulation systems properly**. Ventilation flow rates are expressed as cubic feet per minute per square foot of growing area. Good mechanical ventilation requires the right size fans and/or openings. With passive ventilation it's just openings. An old article by John Bartok, former UConn Extension Ag Engineer, states that roof vent areas should equal the combined sidewall vent area, and each should be at least 15% of the floor area. That seems like a lot, and it suggests that many high tunnels have insufficient passive ventilation. Guidance for circulation flow rates is 25% of the overall growing volume per minute. See Chris Callahan's blog post on greenhouse ventilation for summary of how to size these systems.

8. **Have furnaces professionally serviced** before the heating season. Quoting John Bartok once again: "Keeping the greenhouse heating system in good repair and operating condition can save money in several ways. Fuel consumed may be reduced as much as 20 percent. Heat distribution may be more uniform resulting in a lower thermostat setting and better plant growth. The system is less likely to fail causing crop losses." Servicing furnaces is important to prevent ethylene damage that can result from cracked heat exhangers or improper combustion gas exhaust. Here's a checklist for heating system maintenance.

9. **Seal gaps to avoid heat loss**. Whether you heat a high tunnel with solar energy alone or with supplemental heat, avoiding heat loss at night and on cold days is a good thing. I've seen many tunnels with gaps around doors and roll up sides, and louvers that don't seal. Some growers use old drip tape or used bicycle tire tubing as weatherstripping in door frames. Some brands of ventilation louvers work better than others (see Chris Callahan's blog post, above). And it's standard to have an extra panel of plastic cover left in place that overlaps with each end of the roll-up side, to create a better seal at the corners of a tunnel.

10. **Prepare for climate extremes**. The weather is getting whackier. Large, sometimes rapid, fluctuations in temperature and precipitation make tunnel growing more and more attractive compared to the field, but tunnels are not immune from extreme weather impacts. Options for coping include perimeter drainage, perimeter insulation, shade cloth, shade spray or paint. And don't forget to plan for worst case winds and heavy snow load to avoid collapse of tunnel structures.

11. **Thoroughly mix soil to re-distribute salts** that have moved up to the surface. A SARE-funded research project conducted by UMaine, UNH and UVM found that during winter months, high tunnel soil can became strongly stratified in terms of soluble salt levels. In two test sites, there was a 10-fold difference in soluble salts between measurements from the top inch of soil vs. a sample 2-3 inches deep. This has implications in terms of soil sampling and seed germination. Although no-till has many upsides, it may not be appropriate in tunnels. Mix your tunnel soil well before testing it or sowing crops.

12. **Soil test**, well in advance of planting seeds and transplants. For in-ground vegetable production we recommend the use of both the saturated media extract (SME) and the regular field soil test (modified Morgan's extract) to assess the levels of soluble and reserve nutrients, respectively. The UMaine Testing lab offers a "combined high tunnel package" for $30 that includes both tests. SME also measures soluble salts and soluble forms of nitrogen.
The SME was developed as a potting soil test, it should be used to test your potting soil mixes well in advance of planting to avoid problems. The cost is $18 at UMaine, and many other labs also offer this test. Leaf sampling for long-season crops like tomato is the best way to know what the plants actually take up from the soil. Cost is $27 per sample from DairyOne and other labs.

13. **Apply plenty of K** but avoid fertilizers with large granules. The study cited above found that 500-600 lbs./acre of applied K minimized yellow shoulder and maximized yields of high tunnel tomatoes. Potassium sulfate, a common tunnel fertilizer, varies widely in particle size, and this affects solubility and release rate. When fertilizer with very large particles (several mm diameter) was applied, some large particles were still intact 2 years after application. These would not be available for plant uptake despite being measured by soil tests. When incorporating fertilizers like potassium sulfate, it is advisable to use "fines" that are formulated for more rapid solubility.

14. **Test your irrigation water**. In the high tunnel, irrigation is the only source of water whereas for crops grown outside, irrigation water is diluted by rainfall. It makes sense to test your tunnel irrigation water to optimize yields and to avoid potential toxicity issues. Penn State's guidance advises testing water for pH, alkalinity, conductivity, hardness, chloride, and sodium at a minimum. Their lab offers irrigation water tests starting at $35. Their fact sheet shows the ranges found in over 400 water tests submitted, which provides some idea of the variation out there. If you water has high alkalinity, this UMass fact sheet offers management guidance.

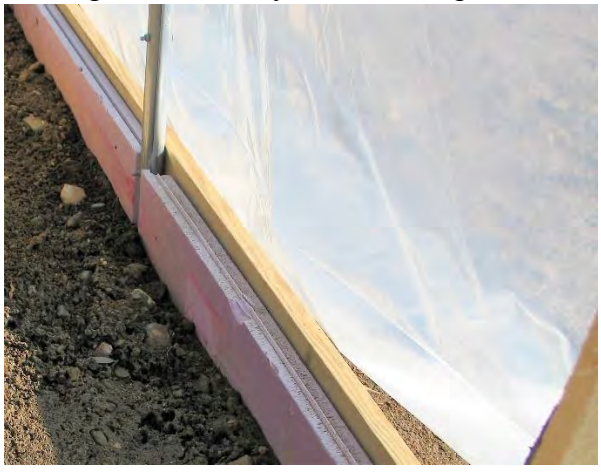
15. **Evaluate and possibly adjust planting density**. High density plantings can increase yield, as Becky Maden's on-farm research with high tunnel tomatoes has shown. Highest yielding tunnels typically had 4 sq. ft. or less per tomato leader. Similarly, packing leafy greens into tunnels, even eliminating walkways, can also increase yield. Of course, high densities reduce air movement and may increase foliar disease, thus the importance of air ventilation and circulation.

16. **Use "guardian plants"** as part of your IPM program. Guardian plants help protect plants by supporting biological control agents that kill pests. For example, marigolds can be used to manage western flower thrips in combination with predatory mites and a granular form of a commercially available insect-killing fungus to create a self-sustaining IPM system. The UVM Entomology Lab offer this do-it-yourself guide. If you've ever had thrips in your tunnels, you know they can be difficult to control.

17. **Establish a pest monitoring and scouting program**. Using traps and inspecting plants on a regular basis can keep pest problems from becoming unmanageable. Consider assigning one person to be your "IPM scout" performing a weekly walk-through of all tunnels, documenting insect and disease populations, and taking pictures of any symptoms needing identification. UMass Extension has a simple scouting form for common greenhouse insect pests. Yellow sticky cards are handy monitoring tools, but they require getting familiar with what gets stuck on them; see guidance like this from NC State Univ. There are many biological control options for tunnels and greenhouses. These should be preordered in many cases. You can store ladybugs in a fridge if you have a history of aphid problems.

18. **Install sensors and alarms**. An air temperature alarm and an emergency heater are basic examples of this, but there are many more options for monitors, which should be associated with backup systems or plans in the event of a system failure. Sensors to consider for tunnels are air temperature, soil temperature, relative humidity, irrigation water tank temperature, water pressure, electric voltage, door open/close, carbon monoxide, propane tank level and more. For more info on remote monitoring see the UVM Ag Engineering blog post.

19. **Minimize 'edge effect' yield losses**. Reduced growth of crops in beds or rows along tunnel edges is common and can be due to several factors. Cold water infiltration occurs if the tunnel wasn't elevated above the surrounding ground. To avoid this, the tunnel should be built on an 8 to 12-inch elevated pad. Excavate a 12-foot wide 6 to 8-inch-deep swale along the length and use the excavated topsoil on top of the tunnel footprint. Rains and snow melt runs off into the swale rather than under the baseboard and into the tunnel. Cold air infiltration from outside soil can be reduced with rigid perimeter insulation placed in the ground 12 to 18 inches deep (be careful not to loosen ground posts). HAF fans can prevent pockets of cold air at tunnel edges (see above). Avoid uneven distribution of nutrients, especially when spreading bulk materials like compost. And be aware of less attention to and care of outside rows simply because it's often harder to work along the edges of the tunnel. Whatever the reasons, the total loss of yield along both tunnel edges over time can be significant, so try to avoid the possible causes.



20. **Prepare for rodent control** (they can move in fast). Options includes active measures like traps, rodenticides, cats, etc.) and passive measures like sealing doors, packing up produce, hardware cloth for exclusion, accepting the loss, selling everything early. For more info on these options see a detailed post on the UVM Ag. Engineering blog.

21. **Enhance labor efficiency**. Take a step back and consider ways to perform tasks more efficiently. Start with tasks that require a lot of time. How long would it take for a flat filler to pay back? How much walking could be avoided when harvesting with the use of carts, or a trolley conveyor? Do you have written standard operating procedures, or SOPs, to support workers in performing time-consuming tasks efficiently? Check out this overview of ways to lower greenhouse labor costs by, you guessed it, John Bartok. The short section on workstation design for repetitive tasks is worth a read for most growers.

22. **Set up systems to track what you want to improve**. As Yogi Berra once said, if you don't know where you're going, you'll probably get there. Want to improve the yield of a crop, or the amount of time spent on certain tasks? You'll need to have a baseline. Weighing all harvests and timing all tasks is unrealistic, so start with the most important crops and tasks, and set up a simple way to measure them. It could be by counting boxes or other units of harvest over time, perhaps from one representative area of a tunnel. How will data be recorded? Maybe old-fashioned clipboards with harvest tally forms, or dry-erase boards, or iPads with spreadsheets. Set up a system that works for your farm.

Bonus points: Take time to celebrate. The world's a crazy place and you and your team are doing good by growing plants that help people stay healthy in body and spirit! It's important to acknowledge this meaningful work--however you choose to do that.

1/7/22

COOPERATIVE EXTENSION SERVICE
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SOIL TESTING:

What It Is and What It Does

W.O. Thom, K.L. Wells, L.W. Murdock, and F. Sikora, Department of Agronomy

What Is Soil Testing?

Soil testing is a special chemical analysis that provides a guideline for lime and fertilizer needs of soils when considered in conjunction with post-fertilizer management and cropping history. A soil testing service is available to every Kentucky citizen through the University of Kentucky Agricultural Experiment Station and Cooperative Extension Service. There is a small service charge to cover the cost of handling and laboratory operation.

Why Soil Test?

Different soil types, different fields, and often areas within the same field vary in the availability of plant nutrients. Also, a field may contain a low level of one nutrient and a high level of another nutrient. Such variations are usually due to differences in:

- previous fertilizer and lime applications
- cropping history
- nutrient contents of the parent materials, and
- losses of surface soil through erosion.

Soil testing is the best way to identify these differences and to adjust liming and fertilization practices.

Soil test results should be included in a record system for each production field on a farm, along with the amounts of lime and fertilizer applied each year, the crops grown, and the yields obtained. In an effective sampling program, each production field should be tested at least every three to four years. Some intensive cropping systems should be sampled every two to three years. Annual sampling is preferable for high cash crops, e.g., alfalfa and double-crop silage production. Only through such a record system can fertility and/or production levels be monitored over time. This is valuable information when making decisions on fertilizer investments and production practices.

How Does It Work?

Soil samples, carefully collected according to instruction (see Kentucky Cooperative Extension Service publication AGR-16, *Taking Soil Test Samples*), are delivered with the necessary information to the local county Extension office. Samples are then sent to the laboratory for testing. After considering soil test levels, past fertilization and liming, cropping history, and the crop to be fertilized or limed, county Extension agents base their lime and fertilizer recommendations on guidelines in Kentucky Cooperative Extension Service publication AGR-1, *Lime and Fertilizer Recommendations.*

For correct lime and fertilizer rates, the soil test must be calibrated with crop yield responses to lime and fertilizer applications. Personnel from the University of Kentucky Department of Agronomy annually conduct field experiments throughout Kentucky to provide a basis for the guidelines published in AGR-1. Recommendations in AGR-1 apply only to test levels obtained in laboratories under supervision of the University of Kentucky College of Agriculture and **should not be used for soil test values from any other laboratories where testing procedures may differ.**

What Tests Are Made?

- **Routine Soil Test**—All samples tested by the University of Kentucky labs are routinely analyzed for pH (water), pH (buffer), and extractable phosphorus, potassium, calcium, magnesium, zinc, and an estimated CEC.
- **Greenhouse Saturation Test**—This special test includes pH (water), pH (buffer), nitrate-nitrogen, soluble salts, and extractable phosphorus, potassium, calcium, and magnesium.
- **Other Special Tests**—See your county Extension agent for details.

Why Is Additional Information Needed?

Along with the soil sample, you need to submit the appropriate "information form" (available at your county Extension office) for either:

- agricultural soils
- home gardens, lawn, and turfgrass
- commercial horticultural crops, or
- greenhouse crops.

Your county Extension agent needs the information on the appropriate form to make recommendations.

What about Nitrogen Tests?

Neither the amount of organic matter nor the amount of nitrate has proven to be a reliable indicator of available nitrogen for field crops grown under Kentucky conditions. For this reason, present nitrogen recommendations for field crops are based on past cropping history, soil management, soil properties, and experimental data.

The University of Kentucky Soil Testing Lab does provide an optional "organic matter" and a "greenhouse saturation" test (the latter includes nitrate-nitrogen). These tests are most useful for greenhouse, landscaping, and specialty crops. However, the nitrate-nitrogen results from this test may be used in unusual situations to help determine if large amounts of nitrogen have been lost during extended wet periods or flooding, or if nitrogen levels are adequate for crop growth from heavily manured fields.

More recently, some states have used soil nitrate concentration when corn is 8 to 12 inches high to adjust N fertilizer rates at sidedressing. Kentucky has limited research data to demonstrate consistent results from this testing. The greatest opportunity for this test may be in fields receiving manure or organic N nutrient sources.

What about Tests for Secondary Nutrients and Micronutrients?

Predicting deficiencies for secondary nutrients and micronutrients from a soil test is much more difficult than for the major nutrients. Most micronutrient tests and recommendations were developed for specific soil types and conditions, and it is difficult to adapt these tests to a wide range of soil types and other conditions.

Calcium and magnesium levels are determined routinely in the Soil Testing Lab. Calcium deficiency in field crops has not been observed in Kentucky. Many field trials have been conducted with applications of magnesium on several Kentucky field crops. These trials have shown only slight yield increases at a few locations where testing has indicated extremely low magnesium levels and have shown no response to additional magnesium at locations with low magnesium soil tests. However, the soil test will indicate when the possibility of a response exists.

The **zinc** test can detect low soil levels but does not always reliably determine when crop yield responses will occur in a specific year. As in the case for many of the micronutrients, weather and soil conditions strongly influence the availability of soil zinc to the plant. Field trials in Kentucky have indicated that low zinc test levels in Central and South Central counties are more likely to indicate zinc deficiency (corn and snapbeans) than in other areas of the state. Low zinc levels combined with high phosphorus and pH levels are usually associated with zinc deficiency. Guidelines for interpreting the zinc soil test for corn are listed in AGR-1.

Deficiencies of **boron, molybdenum, and manganese** in certain crops do exist in some areas of Kentucky. Because of the rather specific crop needs for boron, molybdenum, or manganese, producers should contact their county Extension agent about the need for these micronutrients.

For field crops grown on Kentucky soils, the addition of **iron, copper, or sulfur** has resulted in no measured yield increase. The University will continue to monitor these nutrients in crops and soils but will not offer testing until economic yield or quality increases have been shown.

What Is Cation Exchange Capacity?

Because of the negative charges in their chemical structure, most clay minerals and soil organic matter have the ability to attract or retain positively charged ions (cations) of calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^{+}), aluminum (Al^{+++}), hydrogen (H^{+}), and others. Attraction between the clay minerals and these ions is weak enough that an exchange between ions can occur; those ions most strongly attracted or occurring at higher concentrations in the soil solution may displace other ions from exchange "sites" on the clays.

The capacity of a soil to retain cations under specific conditions is called the "cation exchange capacity" (CEC). This property affects the availability of potassium, calcium, and magnesium to plants. The term used to report CEC is milliequivalents/100 grams (me/100g) of soil.

A recent addition to the Kentucky soil test results reports a "calculated CEC" that uses results from the current extractant in the Kentucky Soil Test Lab (Mehlich III). This extractant is different from most standardized research procedures used to measure CEC. The information on the soil test report is strictly an "estimate" of potentially exchangeable ions based on the amount of potassium, calcium, and magnesium extracted by the Mehlich III extractant, and an "estimate" of hydrogen from the buffer pH reading. Therefore, the CEC reported as part of the soil test results is usually higher and should not be directly compared to results conducted by the research method.

Fortunately, most Kentucky agricultural soils are rather uniform in their CEC due to the vast majority having a silt loam texture. The few high-clay soils occurring in certain areas have much higher CEC's, and the rare sandy loams have much lower CEC's. Because these variations are localized, county Extension agents can use their personal knowledge of the local soils to make any adjustment in fertilizer rates for those occasional soils with unusually low or high CEC's.

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Martin-Gatton College of Agriculture, Food and Environment | Division of Regulatory Services

Submit samples through your county Extension office.

County Code: | | | |

Soil Testing—Commercial Horticulture Submittal Form (CH)

A routine soil test will be conducted. Your report will show Phosphorus, Potassium, Calcium, Magnesium, Zinc, pH and buffer pH.

Name _____ Email _____

Address _____

City _____ State _____ Zip Code _____ Phone: _____

Number of Samples: _____

Enter codes from page 2

Multiple crops can be entered for each sample.

County Sample #	Optional Tests (Extra fee applies)	Owner Sample ID	Acres	Primary Crop (Required)	Primary Mgmt.	Irrigation	Soil Drainage	Previous Crop	Previous Mgmt.

Extension office use: Report sent:

Date Received: Received by: Date Entered: Date Paid:

Lab use:

Date Received: Received by: Lab #(s) : Billing Code:

Martin-Gatton College of Agriculture, Food and Environment | Division of Regulatory Services

Soil Testing—Commercial Horticulture Submittal Form Selections

Optional tests may be added to any sample.

-- Optional Tests -- (Extra fee applies)	
05 - Heavy Metals (Cadmium, Chromium, Copper, Lead, Nickel, Zinc)	BO - Boron
07 - Soil Texture (Sand, Silt, Clay & Textural Class)	OM - Organic Matter
23 - Micronutrients (Boron, Copper, Iron, Manganese)	PA - Potential Acidity (mine spoils)
NR - No routine test	SS - Soluble Salts
	PB - Lead

See our price list for additional tests. https://www.rs.uky.edu/soil/forms/pricelist.pdf
Call the lab for submittal instructions when ordering tests not listed above.

This information is needed to customize recommendations.

-- select Crop -- (Primary Crop Required)			
Annuals	Currants and Gooseberries	Plums	Sweet Potatoes
Apples	Eggplant	Potatoes	Sweet Sorghum
Asparagus	Grapes	Pumpkins	Tomatoes
Azaleas	Greens (collards, kale, etc.)	Raspberries	Tomatoes, High Tunnel
Beans (snap, dry, lima etc.)	Hollies	Rhododendrons	(Recommend Soluble Salts optional test)
Blackberries	Okra	Rhubarb	Trees, Broadleaved Evergreen
Blueberries	Onions (green & bulb)	Root Crops (beets, carrots etc.)	Trees, Conifers (junipers)
Bulbs	Other (no recommendations)	Shrubs, Broadleaved Evergreen	Trees, Conifers (not pines or junipers)
Cantaloupes	Peaches	Shrubs, Deciduous	Trees, Conifers (pines)
Cherries, Tart	Pears	Snap Peas	Trees, Deciduous
Cole Crops (broccoli, etc.)	Pecans	Southern Peas	Walnuts
Corn, Sweet	Peppers (bell & pimento)	Squash	Watermelons
Cucumbers	Perennials (not bulbs)	Strawberries	

-- select Management --	
BS -	Bare sod: Maintaining soil free of vegetation except turfgrass.
BPM -	Black plastic mulch: Using black polyethylene film to enhance plant growth.
CT -	Conventional Tillage: Intensive soil cultivation for seedbed preparation and weed control.
LT -	Limited Tillage with no weed control: Reduced soil disturbance without specific weed control measures.
LTW -	Limited Tillage with weed control: Reduced soil disturbance with weed management strategies.
NT -	No Tillage: Planting crops directly into untilled soil with crop residues on the surface.
OM -	Organic mulch: Using natural materials to cover soil and suppress weeds.
SN -	Sod Nursery: Growing turfgrass sod in a controlled environment for transplantation.
SO -	Sod Orchard: Integrating turfgrass management within orchards to benefit trees.
TNW -	Tilled Nursery with weed control: Combining soil tillage with comprehensive weed management.

-- select Irrigation --	
IR -	Irrigated
NI -	Not Irrigated

-- select Soil Drainage --	
MW -	Moderately Well Drained
PD -	Poorly Drained
SP -	Somewhat Poorly Drained
WD -	Well Drained

UK COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF KENTUCKY — COLLEGE OF AGRICULTURE

Taking Soil Test Samples

W.O. Thom, G.J. Schwab, L.W. Murdock, and F.J. Sikora

The most important part of making fertilizer recommendations is collecting a good, representative soil sample. Soil test results and fertilizer recommendations are based solely on the few ounces of soil submitted to the laboratory for analysis. These few ounces can represent several million pounds of soil in the field. If this sample does not reflect actual soil conditions, the results can be misleading and lead to costly over- or under-fertilization. It is necessary to make sure that the soil sample sent to the laboratory accurately represents the area sampled.

Sample Timing

Soil samples can be collected through much of the year, although fall (September to December) or spring (February to April) are the best times. Fall sampling will often result in a faster return of results and recommendations. Fall sampling will also allow the grower time to have the fertilizer applied well before planting the next crop. However, fall sampling results in lower pH and soil test K levels when conditions are dry. In either case, a field should always be sampled the same time of the year in order to make historical comparisons.

Most fields should be sampled every three to four years. High-value crops, such as tobacco, commercial horticultural crops, alfalfa, red clover, and corn silage, should be sampled annually so that plant nutrient levels can be monitored more closely. Application of manure can change soil test phosphorus, potassium, and zinc levels dramatically, so sampling manured fields each year is also recommended.

Tools You Need

A soil probe, auger, garden trowel, or a spade and knife are all the tools you need to take the individual cores that will make up the "field" sample (Figure 1). You will also need a clean, dry, plastic bucket to collect and mix the sample cores. Be sure not to use galvanized or rubber buckets because they will contaminate the sample with zinc. Soil sample boxes or bags and information forms for submitting samples are available at all county Extension offices.

Collecting Field Crop Samples

An individual sample should represent no more than 20 acres except when soils, past management, and cropping history are quite uniform. The most representative sample can be obtained from a large field by sampling smaller areas on the basis of soil type, cropping history, erosion, or past management practices (Figure 2). For example, a portion of a field may have a history of manure application or tobacco production while the other part does not. Phosphorus and potassium levels will likely be higher in these areas, causing the rest of the field to be under-fertilized if the field is sampled as one

Figure 1. A soil probe, auger, or spade and knife should be used in sampling soils. The spade sample must be trimmed as shown.

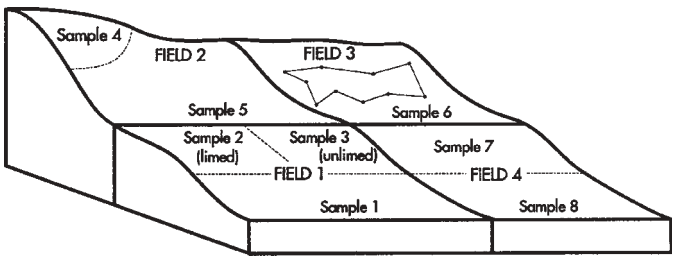

Figure 2. This shows how four fields might require the analysis of one to three composite samples for determining fertility needs. Each composite must contain 10 or more cores, as shown for Sample 6 in Field 3.

unit. It is much better to collect separate samples from these areas because their nutrient requirements are likely quite different from the rest of the field.

If a few years of yield maps are available, these can help identify areas of the field that should be sampled separately.

Soil sampling can also be used to "troubleshoot" areas of the field that are visually different or are consistently low yielding when compared to the rest of the field. Take a sample both from the poor growing area and adjacent areas of good growth. Keep good records indicating where each sample was taken.

Collect at least 10 soil cores for small areas and up to 30 cores for larger fields. Take the soil cores randomly throughout the sampling area and place them in the bucket. **Do not sample:**

- back furrows or dead furrows,
- old fencerows,
- areas used for manure or hay storage and livestock feeding, and
- areas where lime has been piled in the past.

Grid Soil Sampling

With new advances in agriculture and the availability of global positioning satellites, it is now possible to divide a field into smaller units or grid cells that can be sampled individually. Soil test results from each grid can be used to prepare nutrient availability maps of fields. Variable-rate fertilizer and lime applications are then based on these maps. Grid soil sampling and prescription fertilizer maps may result in more accurate recommendations and may lead to greater efficiency in fertilizer use.

Currently the industry standard grid size is 2.5 acres, but Kentucky research shows that variability within areas as small as one acre can be as great as the variability within the entire field. Because soil variability is so high, it is important to treat each grid cell as a field. At least 10 random samples should be collected across the entire grid cell, rather than a few cores from the center of the grid (Figure 3). Grid sampling can be a good way to identify old field boundaries or parts of fields that have had different management in the past if they are unknown to the current producer. This intensive sampling is costly, and limited Kentucky research has not shown a predictable economic benefit when it is compared to the current recommended method of sampling according to soil type, past history, or past management zones.

Sampling after Banded Fertilizer Applications

Care must be taken when sampling no-till fields that have had fertilizer applied in bands rather than broadcast. Phosphorus, potassium, and zinc are immobile in the soil and remain in the concentrated band for several years after application. If these bands are completely avoided during sampling, soil test results will be lower than "actual," leading to over-fertilization. If bands are included too often, soil test results will be higher than "actual," causing an underestimation of fertilizer needs for the crop.

When the location of the bands is known, it is best to sample in the band one time for every 20 cores taken. If the location of the band is unknown, it is best to take pairs of random samples. The first core is completely random, and the second core is taken one-half the band spacing distance in a direction perpendicular to the band direction. For example, if banded fertilizer was applied on 30-inch spacing, the first core would be randomly selected, and the second sample would be taken 15 inches away (perpendicular to the direction of the band). This process would be repeated at least 10 times in a small field and up to 30 times in a larger field. The more cores that are collected, the more closely the sample will represent "actual" field conditions.

Collecting Lawn or Garden Samples

Sample gardens, lawns, and landscaped areas separately. Collect cores randomly from each area. The area to sample for trees includes the soil below the width of the tree. For shrubs, flower beds, and gardens, sample just the soil where the plants are growing. You should sample problem areas and areas with shrubs, trees, or flower beds separately from other turf or lawn areas. **Do not sample:**

- compost areas,
- under the drip-line of trees, and
- close to driveways or streets.

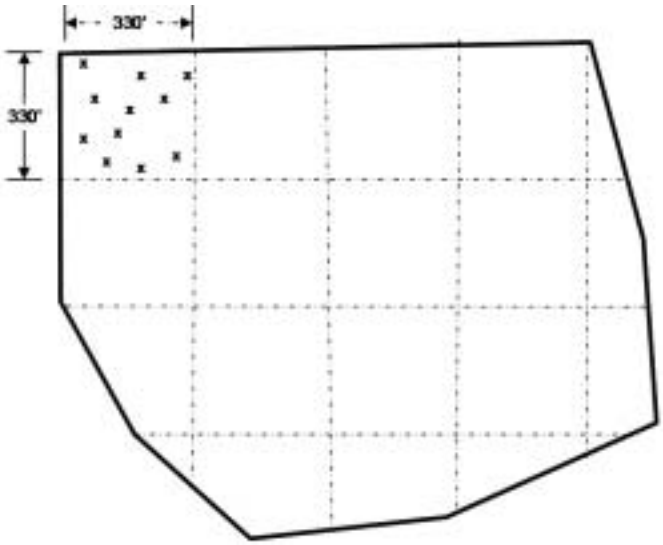

Figure 3. A field can be divided into 2.5-acre grid cells, as shown in the diagram above. Each cell should be treated as an individual field, and approximately 10 random cores should be taken from each cell.

Sample Depth

One commonly overlooked component of soil sampling is the depth of soil to be tested. Most plant nutrients accumulate at the soil surface. This nutrient stratification is a result of past broadcast fertilizer applications and decomposition of plant residue on the soil surface. Because there is a higher concentration of nutrients on the soil surface, soil test values usually go down as the sample depth is increased. To obtain accurate and consistent (between different years) results, samples must be taken to the following depths for these areas:

Tilled Areas—Take soil cores to the depth of the tillage operation (usually 6 to 8 inches).

Non- or Reduced-Tilled Areas—Take soil cores to a depth of 3 to 4 inches for pastures, no-till planting (where fertilizer or lime remains on the soil surface), and minimum-till planting (where fertilizer is incorporated only in the surface 1 to 2 inches).

Lawns and Turfgrasses—Collect soil cores to a depth of 3 to 4 inches.

Sample Preparation

After all cores for an individual sample are collected and placed in the bucket, crush the soil material and mix the sample thoroughly (Figure 4). Allow the sample to air dry in an open space free from contamination. **Do not dry the sample in an oven or at an abnormally high temperature.** When dry, fill the sample container with the soil (Figure 5).

Figure 4. Break up clods while a sample is moist, and spread out to air dry in a clean area.

Sampling and preparing the soil for submission is only half of the process. The other equally important part is filling out a sample information sheet so that the desired crop, tillage, and other information can be considered when making the fertilizer recommendation (Figure 5). The sample information sheet contains all the important information required to provide accurate lime and fertilizer recommendations. Sample information sheets for the University of Kentucky Soil Testing Laboratory can be found at www.rs.uky.edu. The types of forms available are the:

- agricultural form,
- home lawn and garden form, and
- commercial horticulture form.

Figure 5. Thoroughly mix the air-dried sample, fill the sample bag or box, mark with your sample designation, fill out the information sheet, and take the sample to your county Extension office.

Each form asks for primary and alternative crops, as well as other background information. The amount of background information needed depends on the crop to be grown. Table 1 is provided as a guide to the background information needed for major agricultural crops (a) and home lawn and garden plants (b). Help on filling out the forms can be provided by your county Extension office.

It is very important to complete the pertinent sections of the sample information form. This will assure that you receive the most accurate fertilizer recommendations possible. Soil samples should be taken to your county Extension office; from there they will be sent to the UK Soil Testing Laboratory. Results and recommendations will be e-mailed to the county office usually within one to two weeks of submission.

Table 1. List of required crop information for accurate lime and fertilizer recommendations.

A. Agricultural Soil Sample Form

	Primary Crop			
Required Information	**Corn**	**Soybeans**	**Tobacco**	**Forages**
Previous crop	yes[1]	no[2]	yes	no
Primary management	yes	no	no	yes
Previous management	yes	no	no	no
Primary use	yes	no	no	yes
Previous use	no	no	no	no
What was there 2 years ago?	no	no	yes	no
Soil drainage	yes	no	yes	no

B. Home Lawn and Garden Soil Sample Form

	Primary Crop		
Required Information	**Vegetables & Fruits**	**Turfgrass**	**Landscape Plants**
Turfgrass location	no[2]	yes[1]	no
General information	no	yes	no

[1] Yes = Information is needed for accurate recommendations.
[2] No = Information is not needed for accurate recommendations.

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Revised 12-2003

HIGH TUNNEL BEST MANAGEMENT PRACTICES

Long Term Soil Health and Fertility

These best management practices were selected by experienced high tunnel growers and extension staff as a result of a four year project tracking economic, soil and irrigation water data from high tunnels across New York State. They can be used remedially, or implemented in a new high tunnel system.

1 Soil Test Annually and Keep Track of Trends in Major Nutrients

Nutrient levels can shift quickly in high tunnel soils. Fertilizers are often over applied or contain non-target nutrients, leading to nutrient imbalances that impact yields. Keeping track of these levels is a key practice to maintaining productive tunnel soils. An annual soil test and knowing how to manage fertility in response to changing nutrient levels can help prolong the productivity of high tunnel soils.

- Perform an annual soil test at the same time each year with the same lab.
- Keep records of nutrient levels, especially phosphorus and calcium.
- Avoid fertilizers that contain phosphorus and calcium, especially when soil levels are high.
- Test amendments such as composts for these nutrients prior to application.

2 Actively Address and Manage Soil pH, and Irrigation Water pH and Alkalinity

Over half of the tunnels we tested have soil pH higher than 7.0, while the optimal pH range for most crops is between 5.5 and 6.5. Outside of this range, nutrients become less available to the crop and can lead to deficiencies. Keeping track of soil and water pH levels and managing fertility with these levels in mind is crucial for long term tunnel productivity.

- Test soil pH and irrigation water pH and alkalinity annually and keep track of changes over time.
- If either pH is higher than 6.5 and/or seems to be rising over time, consider mitigation efforts.
- Apply elemental sulfur to soil in the fall or spring.
- Add sulfuric or citric acid to irrigation water with an injector throughout the growing season. Consult with local extension staff on injection rates for your water values.
- Leave plastic off for a season to mitigate high pH soils, precipitation is naturally slightly acidic.
- Check the pH of any amendments, weigh the benefits against potential impact on soil pH.

3 Add Organic Matter

Given the intensive nature of high tunnel growing, incorporating organic matter back into high tunnel soils is essential to maintain soil health and productivity. There are a number of effective methods, as well as some pitfalls to be avoided when aiming to increase organic matter levels.

- If organic matter levels are decreasing on soil tests, start adding organic materials to the fertility program.
- Mulch aisles between rows with straw, and turn it in at the end of the season to decompose.
- Amend soil with peat moss, which has a low pH level and does not contribute additional nutrients.
- Incorporate cover crops into the tunnel rotation. More research is needed on the benefits to high tunnel soils of growing a cover crop.
- If compost will be used, test for pH, salt level and nutrient content prior to application.

4 Foliar Test the Crop and Respond to the Results

Foliar testing is key for making sure your crop is getting the necessary nutrients from the soil or fertility amendments and avoid overloading high tunnel soils with excessive inputs. Foliar testing your crop will give you an inside look at how your plants are doing before symptoms arise.

- Check with your local Cooperative Extension office for reputable labs in your state.
- Sample two weeks post-transplant and then every 2-3 weeks throughout the growing season.
- Collect 5-10 of the youngest fully mature leaves from one variety and send to a lab for analysis.
- The lab should provide you with macro and micronutrient levels and recommended ranges for each nutrient, and your local extension agent can help with interpretation of the data.

To watch a short video about this project, go to https://youtu.be/WW-DyFlt0gw

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Cornell Cooperative Extension
Cornell Vegetable Program

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Agricultural Experiment Station

Community Supported Agriculture (CSA) Production Manual of the Organic Farming Unit at the University of Kentucky

Kristi Durbin, Mark Williams, Krista Jacobsen, and Rachel Rudolph, Department of Horticulture

October 2022

Kristi Durbin completed this work in fulfillment of a master's degree of science in integrated plant and soil science. She has worked as the University of Kentucky Community Supported Agriculture (UK-CSA) manager since February 2016. All information gathered for this project was the result of documenting production practices and improvements made since the program's inception.

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Executive Summary

The University of Kentucky Community Supported Agriculture program (UK-CSA), located at the Organic Farming Unit (OFU) of the UK Horticulture Research Farm, has been developing since its inception in 2007. The UK-CSA exists for education, extension, and research, in keeping with the land-grant mission of the university. The farm is one of the only land-grant university teaching farms that is also a commercially productive farm.

The direct marketing model of CSA has risen in popularity over the past three decades. The first CSA programs started in the United States in 1986.[1] Nearly thirty years later, the USDA census reported 7,398 CSA programs in the United States.[2] In Kentucky alone, there are 104 CSA programs tabulated as Kentucky Proud.[3] Agricultural producers entering into the CSA model are expected to have a broad foundational knowledge of annual vegetable production systems. CSA farmers need the skills to provide a consistent supply of diverse, high-quality fruits, herbs, and vegetables for members, which includes knowing how to successfully grow, harvest, process, store, and market over 30 to 40 different crops. This document provides a foundation for CSA producers to learn about farming for a CSA program, from the vantage point of a mechanized CSA production model for 250 members located in central Kentucky.

This manual provides benchmarking for new and established operations; tips for production efficiency; the framework adopted at UK-CSA to run a CSA; and tools that can be adapted and customized to other farms. The tools in this document include templates for planning CSA shares and executing field plans; calendars for keeping production on target; and a fertility planner.

In addition, this manual provides a crop handbook for growing crops for a CSA model. The handbook is the primary resource for daily UK-CSA operations, as it provides a detailed look at how to produce crops in bare ground, plasticulture, and biointensive systems. The handbook outlines best practices for crop management; harvest and post-harvest handling protocols; guidelines for food safety; crop storage requirements; and packaging recommendations. This handbook is a versatile reference for beginning and experienced farmers alike.

Lastly, the manual includes examples of the UK-CSA's standard operating procedures (SOPs) for on-farm management and various production components.

The entire manual can be adapted and tailored to another farm, and it serves as a cornerstone of the Apprenticeship for Sustainable Agriculture course at UK (SAG397) and the UK-CSA hired workforce. This manual is a teaching tool for students, staff, and future farm workers alike.

Previous publications discuss the UK-CSA system. Therefore, this document discusses the updates and additions to the UK-CSA production system since the publication of Economic Analysis of the University of Kentucky Community Supported Agriculture Organic Vegetable Production System (SR-111).[4] In addition, this guidance will be updated to match our system as it undergoes changes. This manual shares a comprehensive, multifaceted tour of the UK-CSA system that can inform and guide a wide audience of growers at different scales and varying levels of experience.

UK-CSA Farming System

CSA Overview

The University of Kentucky's Horticulture Research Farm is managed by the Horticulture Department in the College of Agriculture, Food, and Environment.

The University Farm is located on the unceded ancestral lands of the Hopewell, Adena, Yuchi, Shawnee, Cherokee, and Osage peoples.

A historic farm developed on these lands, which grew hemp and raised horses, until ultimately it came under the ownership and oversight of the Commonwealth's flagship university. This farm has been under the management of the university since the mid-1900s for horticultural research, extension, and education. This 100-acre farm in southern Fayette County houses the OFU, comprising 35 acres of USDA-certified organic land. At the OFU, the UK-CSA program began on a quarter of an acre in 2007, and as of 2021, it manages 10-12 acres for 250 members.

The genesis of the OFU began as a response to the tobacco buyout.[5] With tobacco buyout funds, the OFU began to explore the possibility of organic vegetable production as an alternative to tobacco. The intended demographic was already endowed with land, equipment, infrastructure, and some farming expertise. Thus, from the beginning, the goal of the OFU and CSA programs was to develop a profitable, mid-sized, mechanized, and diversified farming production system. This end goal helped to steer the decision-making process about how the OFU and CSA programs would evolve over time, from scale to equipment acquisition.

Table 1. UK-CSA membership and voucher trends, 2007-2022.

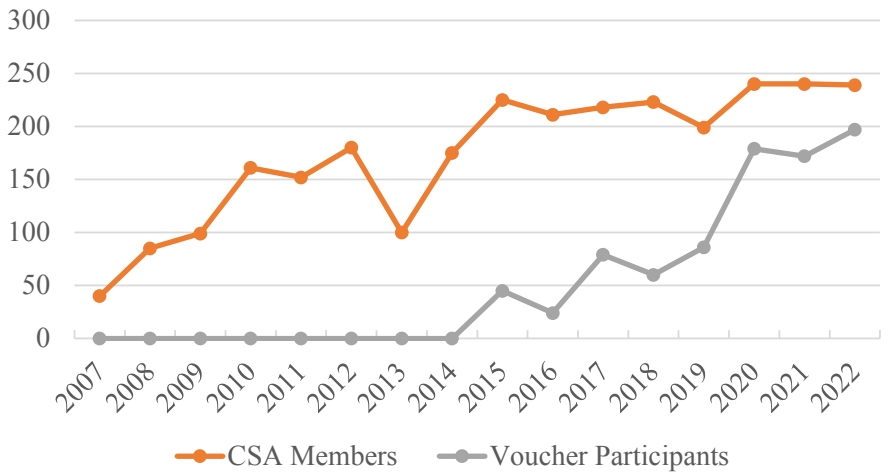


Figure 1. The Organic Farming Unit at the Horticulture Research Farm.

At the start, the CSA was an exploration of the agricultural possibilities for growers across the state in a post-tobacco landscape. Yet this extension-focused purpose was not its sole aim; the CSA has always been a keystone in the formation of an undergraduate degree curriculum in sustainable agriculture and community food systems. As a part of this degree program, students take a 3.0 credit-hour class, Apprenticeship in Sustainable Agriculture, at the OFU, which involves weekly classes and practicum on-farm during the growing season. The UK-CSA strives to be an exemplar of the tripartite focus of sustainable agriculture: environmental stewardship, economic profitability, and social responsibility.

When the CSA began in 2007, there were only 40 shares. Over 15 seasons, membership grew to 250 shares. Over 130 students have completed the apprenticeship in this time. In 2015, the UK-CSA was one of the founding members of the Kentucky Farm Share Coalition , which launched a subsidized voucher program for CSA shares. The Health and Wellness group at the University of Kentucky has piloted this program by offering $200 off the cost of a CSA share as a taxable benefit to UK employees on a health care plan. The voucher recipients represent a portion of total CSA membership. A total of 645 vouchers have been distributed over seven seasons, totaling $129,000 of savings to UK-CSA members.

The CSA is not a student farm; the program is managed with five full-time equivalent (FTE) staff. In order to have consistent production that overlaps with the academic calendar, the CSA needed its own dedicated staff. The goal of economic sustainability also guided this decision, and the full economic analysis can be viewed online.[6]

CSA Model

The hallmark of CSA is variety. The foundation of UK-CSA shares is vegetables. The shares consist of six to 12 different items every week, and the shares are sized to feed approximately four people.

For planning purposes, crops are divided into several categories. The goal for planning CSA shares is to include in each week's share a mix of items that check off as many of these categories as possible for peak variety. These categories are divided as follows: staples, greens, storage, herbs and fruits, specialty items, and other items.

Staples are defined as the tried-and-true vegetables that are crowd-pleasers. These are the crops that everyone will gladly eat, and most members will have the acquired cultural knowledge of how to prepare them with minimal guidance. At UK-CSA, staple crops include broccoli, carrots, green beans, lettuce, sweet corn, tomatoes, peppers, summer squash, and cucumbers.

Greens encompass those items that are generally eaten fresh and for which the shelf life is not as long. Green items include arugula, bok choy, braising greens, cabbage, collards, kale, napa cabbage, salad greens, spinach, and Swiss chard.

Storage crops include roots, tubers, and shelf-stable crops like winter squash that can be stored longer and distributed on a more flexible schedule. The crops that fall into the category of roots and tubers include beets, radishes, rutabagas, potatoes, pumpkins, sweet potatoes, turnips, and winter squash.

Herbs and fruits diversify CSA share offerings. UK-CSA shares include annual fruits, like watermelon and cantaloupe, and one perennial fruit, rhubarb. Herbs in this category include basil, celery, cilantro, dill, garlic, green onion, and onion, as well as occasional perennial and biennial herbs like oregano, parsley, sage, and thyme.

Specialty items are those that are not as familiar to CSA members. These are also crops that tend to be harder to produce within the main season or are more labor-intensive; therefore, from a farming perspective, these items are not ideally included in shares each week—or even every year. However, they play an important role in teaching farmers how to grow something new and introducing CSA members to new crops and flavors. Crops in this category have included artichokes, brussels sprouts, cauliflower, dry beans, edamame, eggplant, fennel, ginger, hot peppers, kohlrabi, leeks, okra, popcorn, snap peas, snow peas, and turmeric.

CSA Planning

The Share and Field Planner workbook is used to project CSA shares and schedule their associated field seedings or plantings. To plan for 22 weeks of the diverse CSA shares that members expect, every crop is designated to be given out for a specific week (or multiple weeks) during the season. The end product becomes the starting point for planning and is developed in the worksheet Projected Shares. There are certain parameters that guide these decisions of the projected weekly shares.

First, the timing of planting and harvesting is considered. Planting calendars for Kentucky are checked.[7] Since the farm is located in central Kentucky, in zone 6b, winter temperatures fall to -5°F on average, and the frost-free period starts around April 20 and ends around October 21. This information informs when certain frost-sensitive crops can and cannot be planted outside. Historical data is referenced to help make accurate predictions for which crops can be reliably harvested at different times of the year. These dates are used to double-check that the projected shares match climatic parameters.

Second, single-harvest crops are differentiated from cut-and-come-again crops in the planting plan. With cut-and-come-again crops (like kale or lettuce mix) or successively harvested crops (like summer squash and cucumbers), the goal is to get as many high-quality harvests as possible from a single planting without overwhelming members with the same items. Single-harvest items and storage crops (like cabbage and head lettuce) are easier to stagger over nonconsecutive weeks.

Third, the goals for CSA box variety aim to supply crops that check as many categories as possible in each week. Some crops (the staples) are included frequently, while others (the specialty items) are included infrequently.

Fourth, some crops are grouped together in a week's share for member advantages. For example, UK-CSA always grows leeks for shares, but members only receive them one or two times per year. Some members are unfamiliar with leeks but may be familiar with leek and potato soup. Therefore, leeks are frequently paired with potatoes for one of the midsummer boxes. As a second example, when tomatoes start coming in strong, some hot peppers are also included with the tomatoes, as a tomato bounty is a prime excuse to make salsa.

The worksheet Target CSA Variety and Timing incorporates these considerations for planned shares and is referenced during the entire planning phase. Once the Projected Shares worksheet is completed, the Crop Plan worksheet can be developed with details for each item, from seed orders to harvest. This spreadsheet is a critical component of the planning process.

The Crop Plan worksheet can be used to calculate how many row feet of the crop should be planted for the CSA share. The share calculation method relies on predictable yield values on a per-row-foot basis. Each season, yield values are revisited and adjusted as needed. Yield values are not replaced entirely each season, as inconsistencies in yield may occur in different years and with different crop varieties; therefore, average values are used. The average value is calculated based on the value used in the planning process the prior year and the actual yield data tabulated for that year, as calculated on the Harvest Log worksheet. For example, with green beans,

the crop yield through 2019 had been averaged at 0.29 pounds per row foot . The actual yield in 2020 for green beans was 0.35 pounds per row foot. Averaging these two values gives a projected yield of 0.32 pounds per row foot going into the next season.

Here are a few rules of thumb to consider in the planning process:

- A 25 CSA-member buffer is added to the plans to account for crop loss or underperformance. In addition, this buffer amount is not wasted, as any surplus can be sold retail through another marketing channel.
- Common sense still informs the decision-making process. If the yield data calculates that only 1.7 rows of a crop are needed to be planted for the CSA, it is more practical to round up to two rows. It is not realistic to plant such precise amounts, especially on a larger scale.
- A buffer for seedling loss in the greenhouse or inexact row measurements in the field is always given. For the greenhouse plans and the direct seeding plans, a preferred buffer amount of 15 to 20 percent is added to the minimum number of plants needed in the field.
- Variety selection is kept simple by changing no more than 10 to 15 percent of crop varieties each year. Limiting the quantity of new varieties trialed each year minimizes risk with an unknown commodity. Establishing a reliable baseline for crop performance is more important than novelty.
- The calculated plant date is the difference between desired harvest date and the days to maturity (DTM). In most cases, this calculated date is inaccurate. Traditionally, days are added in early spring and late fall to account for the cooler temperatures and slower growth. By June, seven to 10 days are subtracted off DTM to account for warmer temperatures and faster growth. The best method for calculating the ideal planting date is by referencing the actual DTM from the prior year's crops. The Harvest Log worksheet reflects the prior year's harvest data to determine which plantings did not mature as predicted, along with actual yield.

Crop Rotation

Crop rotation is a necessity for maintaining soil health and disrupting cycles of diseases and pest pressures. Several methods of crop rotation may be followed. These may include rotation by crop family, by nitrogen requirements, by cover crops and cash crops, by rooting depth, or by seasonality. One rule of thumb is to avoid planting the same botanical family in the same area within four years.

Table 2. Botanical family crop rotation reference.

Botanical Family	*Example Crops in Family*
Solanaceae (Solanaceous or Nightshade)	Potatoes, Tomatoes, Peppers, Eggplant
Fabaceae (Legume)	Peas, Beans, Clover, Vetch
Brassicaceae (Brassica)	Arugula, Broccoli, Brussels Sprouts, Cabbage, Cauliflower, Collards, Kale, Kohlrabi, Mustards, Radish, Rutabaga, Turnips
Cucurbitaceae (Cucurbit)	Melon, Squash, Cucumber, Pumpkin
Asteraceae (Aster)	Lettuce, Artichoke, Radiccio, Sunflowers, Chamomile
Amaranthaceae (Amaranth)	Beets, Spinach, Chard
Amaryllidaceae (Allium)	Onions, Green Onions, Garlic, Leeks, Chives
Convolvulaceae (Morningglory)	Sweet Potato
Poaceae (Grass)	Sweet Corn, Popcorn, Rye, Oats, Wheat, Millet
Apiaceae (Umbel)	Carrots, Celery, Cilantro, Dill, Fennel, Parsley, Parsnips
Lamiaceae (Mint)	Mint, Basil, Rosemary, Sage, other herbs
Polygonaceae (Buckwheat)	Buckwheat, Rhubarb, Sorrel
Malvaceae (Mallow)	Okra
Other	Cover Crops (not cash crops)

Rotation, while necessary, does not always work systematically. A CSA program does not usually grow equivalent amounts of every crop family. In addition, being more land-limited means there is not a guaranteed fallow time for every field every year. While an ideal rotation may be a predetermined four-, six-, or eight-year rotation of vegetables, a static rotation like this cannot be implemented in the farming system. The complexity of a CSA growing system necessitates crop sequencing over crop rotation. The difference is that sequences are determined anew year to year, rather than several years in advance. In addition, smaller areas are considered in the crop sequences, which means that sometimes fields are divided into sections to sequence crops over a smaller footprint.

In addition to rotating botanical families away from the same land area, crops from the same families are not planted in adjacent areas, as adjacent plantings of the same family do not fully disrupt pest cycles. Set sequences are seldom ideal on every farm, but advantages and disadvantages of particular crop sequences do occur, which are noted after observation.[8] Some of the land-based factors considered in sequence planning include: insect pressures, weed pressures, disease pressures (particularly if soilborne), organic matter content, and problem areas (such as those caused by compaction, poor drainage, slope, or exposure to wind).

The crop sequence plan is started by calculating the minimum return time. The minimum return time informs how many years the most limiting crop family can be rotated around the farm. The most limiting crop family is the one that occupies the most land space at a farming operation. To calculate minimum return time, add up the land area occupied by each family. The unit used will be the unit of rotation; generally, this would be crop beds or entire fields. Divide the total number of beds (or fields) planted at the farm by the number of beds occupied by the most land-intensive crop family. The result is the minimum return time, or the number of years the farm can rotate away from the crop family. This number guides all the following crop sequences, as rotation planning always begins by planning sequences with the most limiting family.

At UK-CSA, 25 percent of the acreage is planted in *Brassica* crops. Thus, the minimum return time is four years. If possible, a proactive plan is started to outline fallow years when fields are pulled out of production and planted in a cover crop for an entire growing cycle. Since UK-CSA is land-limited, double-cropping a field (spring and fall, summer and winter) is also done to take the double-cropped field out of production the year following for an entire cycle. Fallow fields are ideally planted with at least three cycles of successive cover crops for maximum soil building.

Table 3. Minimum return time for CSA crop rotation.

Plant Family	*Area*		*Percentage of Total Area*	*Max Rotation Period*
Brassica	61	beds	25.9%	4
Cucurbit	39.5	beds	16.8%	6
Nightshade	26	beds	11.0%	9
Grass	22	beds	9.3%	11
Legume	20	beds	8.5%	12
Umbel	18.5	beds	7.8%	13
Allium	16.5	beds	7.0%	14
Amaranth	13.25	beds	5.6%	18
Aster	10.5	beds	4.5%	22
Morninglory	6	beds	2.5%	39
Buckwheat	1	beds	0.4%	236
Mallow	1	beds	0.4%	236
Mint	0.5	beds	0.2%	472
TOTAL	*235.75*	*beds*	*100%*	

Mapping

Maintaining a historical record of field maps, as illustrated on the two Historical Rotation worksheets, is a helpful tool to inform crop sequencing decisions. By color coding the maps to correspond to botanical family, a glance at each field is a quick guide for the options to maximize botanical family rotations.

After assessing the overarching goals of crop sequences and looking at historical sequences by botanical family, the next step is grouping different plantings together in fields. Field groupings are decided first by botanical family, followed next by dates of planting, and finally by dates of harvest. The goal is to group crops most closely aligned with all three categories before solidifying each field plan. By grouping planting dates close together in a given field, field preparations can be done en masse without leaving too much soil bare and exposed. This also means that the number of cultivation passes to keep weeds under control in those empty beds will be minimized. By grouping harvest dates close together in a given field, fields can likewise be emptied en masse, allowing that entire field to be turned over to a cover crop, rather than having partial fields in cover crops.

Once the field assignments are made, individual maps like the Example Field Map are drafted for each field. These maps inform the entire team about what gets planted where, when, and how. Maps not only show the crop to be planted, but they include the corresponding settings for the equipment. Information on printed maps includes field and planting orientation, crop variety name, target planting date, number of rows per bed, in-row spacing, settings for the vacuum seeder (for direct seeded items), fertilizer requirements and accompanying machine settings for fertilizer output.

Calendars

The completed Crop Plan worksheet is used to draft calendars to keep the farm on track with target planting dates.

- A Field Preparation Calendar is used to give ample time to prepare the field for planting or seeding, as well as to give time for shallow cultivations to reduce weed pressure.
- Planting dates are used to draft a Greenhouse Production Calendar that includes crop variety names, seeding date, tray size, number of trays, and any special instructions.
- A Planting Calendar is drafted to include all crops that are vacuum seeded or transplanted in the ground. Anything scheduled for a given week will get seeded on the earliest day possible for that week, depending on the weather. The Planting Calendar includes crop variety names, seeding and planting dates, field location, rows per bed, and notes.

Table 4. Field preparation scheduling guidelines.

Activity	Time before 1st Planting in Field
Flail Mow	6-8 weeks
Primary Tillage, Bare Ground	4-6 weeks
Primary Tillage, Plasticulture	6 weeks
Secondary Tillage, Bare Ground	Immediately before stale seedbed cultivation begins
Secondary Tillage, Plasticulture	Immediately before installing plastic beds
Stale Seed Bed, Bare Ground	4 weeks (1st pass), Weekly after tillage and before planting (3-4 passes total)
Drip Irrigation Laying, Bare Ground	4 weeks, at time of 1st Stale Seed Bed pass
Plastic Laying	3 weeks
Plastic Cultivation	Weekly after plastic beds installed, until living mulch seeded
Basketweeding/Fingerweeding	Weekly after planting and seeding, depending on crop growth

CSA Crop Management

Greenhouse Production

A controlled environment like a greenhouse gives a jump start on the growing season. Some crops are well suited to transplanting while others are best to be direct seeded, and some are equally suited to either transplanting or direct seeding. On occasion, beets, chard, spinach, and radishes are transplanted, though usually direct seeding is preferred. In addition, cucumbers are usually direct seeded, because they are fast growing and tend to break when transplanted. If cucumbers are given a minimal amount of time in the greenhouse, they can also be transplanted.

Tip: Seeding events are grouped together on the same day as much as possible, so that seeding or planting only occurs one day a week. It is better to seed some crops early to maximize efficiency when considering the time to set up equipment. The primary crops that need to be seeded close to their exact calculated date for days to maturity include sweet corn and green beans.

Transplanting maximizes crop efficiency by starting with a vigorous plant grown in optimal conditions prior to being planted. The risk of transplanting crops is loss through shock as they adjust to outdoor growing conditions. This shock is mitigated by a process known as "hardening off."

Managing the greenhouse production includes seeding crops in a timely fashion, monitoring germination, fertilizing, hardening off appropriately, scouting for any pest or disease issues, and potting up when appropriate. Some crops benefit from developing more extensive root balls by moving them from a small tray size to a large tray size. This practice can be labor-intensive, but the benefits to plant health before the plant goes in the ground make the time investment worthwhile. Crops that will be potted up to a larger tray include herbs, flowers, celery, eggplant, leeks, peppers, and tomatoes. Proper greenhouse management is critical for optimum plant health and vigor; standard operating procedures (SOPs) are useful for training workers.

Table 5. Recommended crop planting methods.

Crop	*Direct Seed*	*Transplant*	*Potting Up*
Arugula	✓		
Basil		✓	
Beets	✓	✓	
Bok Choy		✓	
Broccoli		✓	
Brussels Sprouts		✓	
Cabbage		✓	
Cantaloupe		✓	
Carrots	✓		
Cauliflower		✓	
Celery		✓	✓
Cilantro	✓		
Cucumber	✓	✓	
Dill	✓		
Eggplant		✓	✓
Fennel		✓	
Garlic		✓	
Ginger		✓	
Green Beans	✓		
Green Onion		✓	
Kale/Collards	✓	✓	
Kohlrabi		✓	
Leeks		✓	✓
Lettuce Head		✓	
Lettuce Mix	✓		
Mustard Green	✓		
Napa Cabbage		✓	
Okra		✓	
Onions		✓	
Pepper		✓	✓
Popcorn	✓		
Potato		✓	
Pumpkin		✓	
Radish	✓		
Rutabaga	✓		
Spinach	✓	✓	
Summer Squash		✓	
Sweet Corn	✓		
Sweet Potato		✓	
Swiss Chard	✓	✓	
Tomato		✓	✓
Turmeric		✓	
Turnips	✓		
Watermelon		✓	
Winter Squash		✓	

The quality of the media and length of time a seedling is in a tray will determine frequency of additional fertilizing. Winstrip trays are used at UK-CSA; these trays have a unique pattern on their surfaces that situates each cell next to an air column. Slits in the sides of the cells allow the roots to be "air pruned" and prevent plants from becoming rootbound. These trays are also made of thick plastic that can be washed, sanitized, and reused.

Figure 2. Copies of the greenhouse SOPs and the greenhouse calendar are kept in the greenhouse facility itself. The sheets are placed in a waterproof ticket holder that can be hung on the wall for quick reference.

Figure 3. Onions seeded on the same day, with ProMix potting media used on left and Vermont Compost potting media on right. Neither seeding received any fertigation. Stunting resulted when crops seeded with ProMix were not fertigated on a regular schedule.

There are four standard sizes of trays used, and the numbers correspond to the quantity of cells in each tray. Larger numbers have smaller cells per tray, while smaller numbers have larger cells per tray.

Figure 4. Winstrip tray.

The size of tray used during the seeding depends on the crop, the number of weeks it stays in the greenhouse tray, and the planting method. Crops that take a long time to develop a strong root structure, like herbs, are started in smaller trays. Crops that grow rapidly are sown in a large tray size at the outset. Any crop that will be transplanted into bare ground cannot be larger than one square inch for use with the equipment.

Seeds are stored in airtight containers under refrigeration for optimal performance. Seeds are sorted by crop, placed in labeled and closed poly bags, and grouped into totes for easy organization. Before organizing seeds for storage, notes are made of germination percentages on the package label. Whenever germination percentages are below 90 percent, a larger buffer amount will be given. While crop plans do include a 15 to 20 percent seed buffer, this information can indicate when to adjust seeding rates for different varieties.

Figure 5. Labels facing out on the seed storage totes help workers find the correct seeds quickly.

Many seeds can last several years under proper refrigeration. Based on experience, most seeds are still viable two to three years after their purchase date. The "germ date" listed on the front of a seed envelope indicates when they were last tested and serves as a guide in determining how long to keep seeds past that date. Most herbs are replaced annually, as germination percentages decrease significantly for older seed. In addition, it is best practice to use up any pelleted seed in the year it is purchased. Some seeds also undergo hot water treatment. While it is advisable to use hot water-treated seed in the same season it is treated, no significant germination decreases occurred after holding hot water-treated seed for one whole year.

Seeds can be sown by hand or using a greenhouse vacuum seeder. Refer to the sections on Greenhouse Seeding, Greenhouse Vacuum Seeding, Greenhouse Potting Up, Greenhouse Hardening Off, and Greenhouse Management in the UK-CSA SOP Manual for more information.

Table 6. Greenhouse Winstrip tray selection guide.

Winstrip Tray	*Cell Size*	*Crops*
162	0.9 in^2	Herbs; Germinating Eggplant, Flowers, Peppers, Tomatoes, Onions
128	1 in^2	Basil, Brassicas, Fennel, Green Onions, Leeks, Lettuce
72	1.3 in^2	Melons, Okra, Summer Squash, Sunflowers, Winter Squash; Potting-up Leeks, Flowers
50	1.6 in^2	Potting-up Eggplant, Peppers, Tomatoes

Soil and Field Preparations

The UK-CSA is situated on a Maury silt loam soil. A starting point for understanding more about a farm's soil is the USDA Web Soil Survey (WSS).[9] The WSS identifies soil types and characteristics in given geographic areas.

In addition to identifying soil type and tracking field crop rotation history, notes are made on field characteristics. Some fields are not suited for all types of crops. Factors considered in field analyses include slope, drainage, compaction, aspect, shade, air drainage, visibility, organic matter, tilth, nutrient imbalances, erosion potential, annual weed pressures, perennial weed pressures, disease problems, animal pressures, proximity to landmarks, neighbors, or other farm features like windbreaks or trees. These characteristics indicate limitations as well as opportunities for crop choices in the farm's fields. Here are some examples of how UK-CSA has responded to field characteristics at the OFU:

- One field suffered from an outbreak of Canadian thistle. This field was taken out of production, tilled aggressively, and then planted in heavy rotations of cover crops to smother the thistle. This field is not in production.
- Fields with rhizomatous weed pressure, such as perennial Johnson grass, are ill-suited for direct-seeded crops, especially carrots. Since Johnson grass cannot be killed with flame weeding, the long germination period for carrots will allow the Johnson grass to get a head start.
- One field borders a fence line adjacent to a public park. The proximity of this fence line to the public area made it difficult to find a window of time to reliably spray that field when no person would be affected. This field is now used for crops that do not require frequent spraying.
- One field has a slope of more than 2 percent on the northern third. Due to this slope, plastic mulch-covered raised beds are usually used in this field. Driving bare-ground cultivation implements in this field is challenging, particularly for inexperienced tractor drivers; implements slide across the beds at an angle when driving along the slope and cut into the neighboring beds. With plastic mulch beds, there is wider spacing between them, and erosion potential is minimized by planting a living mulch between the plastic.
- A nutrient deficiency occurred in a field that had used a straw mulch the prior season. This high-carbon mulch did not have enough time to break down when it was time to plant spring crops. This straw tied up some of the fertility, causing severe stunting and yellowing on plants planted in areas where this straw was still present. Fields that use a straw mulch the prior year are given a longer time before the next planting, and if possible, successive annual plantings in these fields are avoided altogether.

Each fall, soil samples from each of the fields or management units are taken and submitted to a lab for analysis.[10] The soil test results guide management decisions for additional fertility required, if any, for the crops that are being grown that upcoming season.

Compost applications are an amendment of organic matter that contributes to a soil's tilth. The tilth of a soil refers to the physical characteristics that contribute to the soil's ability to support the planting and growing of crops. Organic matter additions to the soil will benefit the soil's water- and nutrient-holding capacity, friability, porosity, and particle aggregation, as well as alleviating compaction.

The compost application is completed in fall to guarantee a minimum of 120 days for the pre-harvest interval, the time between manure application and the harvest of crops that come in contact with soil. This longer time frame is necessitated by NOP requirements since the amendment used at UK-CSA is not certified compost.[11]

Figure 6. Soil aggregates are a sign of good tilth.

The desired compost (or manure) application rate is 10 tons per acre, which is applied using an H&S manure spreader Model 125. On a small scale, a drill-powered tool called a tilther incorporates compost into individual beds.

Field preparation involves both primary and secondary tillage operations. The goal of tillage is to prepare a field for the crop to be sown there while minimizing disturbance to the weed seed bank. Soil disturbance will bring weed seeds to the soil surface; therefore, all tillage operations are kept as shallow as possible and tillage passes are kept to the fewest possible to reduce the amount of disturbance.

Every four to five years, fields are prepared by subsoiling in the fall to break up plow pan that can develop over time.

When entering a new field in the following year, the first step is to mow any overwintered cover crops. If the cover crop winter-killed, mowing may be unnecessary unless there is substantial stubble. Thick residues can be broken up by using a chisel plow or a disc harrow after mowing, if needed.

The standard primary tillage pass is accomplished with a spader. The spader works at a depth of four to eight inches, digging into the soil without inverting it. Tines on the back end of the spader finely cultivate the top one to two inches to create a proper planting surface. If a field cannot be put into beds right away, a field cultivator can be used to destroy weeds that pop up until the beds are formed.

Occasionally, planting starts immediately after spading. However, if the soil contains larger clods, a secondary tillage operation with a rototiller may be necessary. While rototilling is more destructive to soil, damage is minimized by proper depth control. Only the top inch of the soil profile is tilled for minimal soil disturbance.

Figure 7. A bucket loader fills the manure spreader before it drives over the fields to spread the composted manure.

Figure 8. Spreading partially composted manure in fields with H&S PTO-driven manure spreader.

Figure 9. The Tilther, sold by Johnny's Selected Seeds, is run on a battery-powered drill. By pulling a rope connected to the drill, the tines are activated and rotate to incorporate compost, soil amendments, or small amounts of residue.

Figure 10. Subsoiler.

Figure 11. Flail mower.

Figure 12. Chisel plow.

Figure 13. Disc harrows.

Figure 14. Imants spader, 27 series.

Figure 16. Field cultivator.

Figure 15. Imants spader, 38 series.

Figure 17. Maschio rototiller.

Bed Installation

Most of the field production at UK-CSA is done in either a bare-ground system or a plastic mulch-covered raised-bed system. For the bare-ground system, a stale seedbed cultivator is used to shape the beds. This implement is also versatile in reducing the weed pressure. By going over the bed with three to four passes before planting, with each pass spaced seven to ten days apart, the weed pressure on that bed will be reduced by 93 to 98 percent.[12]

A 50-foot-wide field can fit 10 bare-ground beds. After the first stale seedbed passes, the beds are set in the field. The initial stale seedbed pass forms a bed top, which also serves as a guide for lining up the subsurface irrigation drip layer. Immediately after installing the subsurface drip lines, the beds are passed over with the stale seedbed implement a second time to smooth the surface. This implement runs on top of the drip lines without snagging or disturbing them, but its weekly use continues to reduce weed pressure prior to planting.

In the plastic system, up to eight plastic beds can fit in a single 50-foot field. Bed centers are marked with flags at even spacings for easy tractor alignment, if needed. Fewer plastic beds per field are preferred for crops like tomatoes that benefit from increased air circulation to minimize disease pressure.

Figure 18. Custom stale seedbed cultivator.

Figure 19. Ten bare-ground beds ready for planting.

Figure 20. Custom Andros subsurface drip layer.

Some crops are best suited for different types of plastic mulch. Three types used include: black, white, and aluminized. Black is best suited for crops that are heat loving. White is preferred for crops that benefit from more reflectivity or for slightly cooler temperatures in midsummer. Aluminized plastic is useful for repelling insect pests like thrips and flea beetles. Netting the crops controls insect pests when susceptible crops are not grown on reflective mulch.

Tip: Be sure that workers wear sunglasses when installing aluminized plastic mulch. On a sunny day, it is highly reflective.

Figure 21. Keeping plastic beds straight at installation with visual guides.

Figure 22. Aluminized plastic.

Table 7. Plastic mulch selection by crop.

Plastic Mulch Selection	
Black	Early Tomatoes, Eggplant, Flowers, Garlic, Herbs, Peppers, Summer Squash, Sweet Potatoes, Watermelon
White	Cantaloupe, Late Tomatoes, Winter Squash, Garlic
Aluminized	Cantaloupe, Eggplant, Onions, Summer Squash, Winter Squash

For smaller, intensively planted areas like high tunnels, tillage is managed with a walk-behind tractor (BCS) and an assortment of implements. The primary bed preparation implements used with the BCS walk-behind tractor include a flail mower, rotary plow, tiller, and power harrow. Quick bed turnovers are managed by using a broadfork or digging fork to break compaction, and minimize tillage passes.

Table 8. Plastic mulch installation spacing by crop.

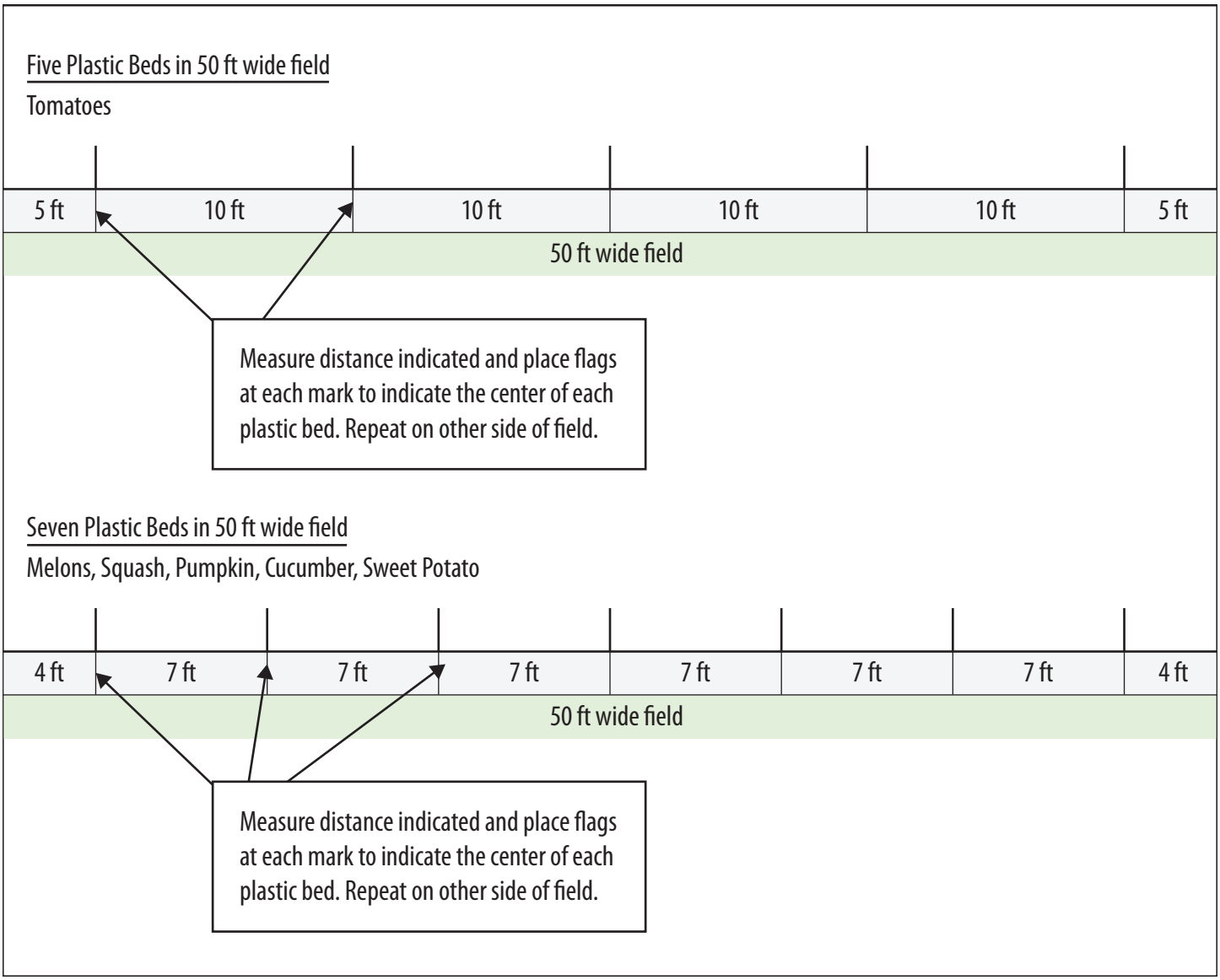


Figure 23. A broadfork is used to alleviate compaction between succession plantings on smaller beds.

Figure 25. BCS flail mower.

Figure 24. BCS rotary plow.

Figure 26. BCS power harrow.

Planting

UK-CSA utilizes three distinct planting systems. The standard is the bare-ground system, with two rows of crops per bed measured at 18 inches apart. These beds are either planted by direct seeding with a MaterMacc Precision Vacuum Seeder or MaterMacc VegiMacc Vacuum Seeder, or by transplanting with the Mechanical Transplanter 5000.

The second planting system is plasticulture. The use of black, white, or aluminized plastic mulch conserves water and reduces weed pressure. Plants are hand transplanted into the plastic beds, often with the aid of a Rain-Flo Model 1600 water wheel transplanter.

The biointensive planting system is the third planting system, which utilizes multi-row beds, shorter in length, and packs more crops on a smaller land footprint. Crops are hand planted using trowels or soil knives, or they are seeded using a Jang JP-6 push seeder. This system is similarly applied within controlled growing environments, including both high tunnels and a solar greenhouse. Beds can be marked for planting using a seedbed roller with dibblers or a bed preparation rake with extended tines for row markers. These tools facilitate seeding and transplanting with even spacing in-row and/or between rows.

Figure 27. The MaterMacc VegiMacc vacuum seeder.

Figure 28. Mechanical Transplanter 5000.

Figure 29. Rotating carousel holds individual plants.

Figure 30. Plant plugs drop down chutes and get a spurt of water before being buried.

Figure 31. The Rain-Flo Model 1600 water wheel can hold one to three wheels for one- to three-row production systems. The wheel punches a hole into the plastic and creates a dibble, while a stream of water is sent into the hole.

Figure 32. Workers wear nitrile gloves to push plants in the plastic bed by hand.

Figure 33. The 36-inch seedbed roller packs bed tops while dibbling holes. Dibble spacing is customizable.

Figure 34. Bed preparation rake.

Figure 35. A six-hopper Jang push seeder can seed between one and six rows per bed at a time.

Cover Crops

A cover crop is any cover that is intentionally planted into the farming system for benefits other than that of a cash crop. Cover crops serve several valuable roles in the farming system:

- Covering soil to prevent wind and rain erosion, particularly in the off-season
- Adding organic matter back to the soil for benefits of water-holding capacity, porosity, soil aggregation, and feeding of microbial life
- Alleviating soil compaction
- Providing a nitrogen boost to the soil through leguminous crop nitrogen fixation
- Reducing leaching of nitrogen by scavenging for nitrogen in the soil
- Inhibiting weed germination via allelopathy
- Attracting pollinators and providing refuge for beneficial insects
- Contributing to the farm's overall crop rotation plan
- Outcompeting and suppressing weeds

Cover crops can be categorized as leguminous or nonleguminous. Leguminous cover crops grown include clovers, vetches, peas, and sunn hemp, all of which will add nitrogen to the system when terminated at the proper time.

Nonleguminous cover crops include millet, barley, oats, wheat, annual ryegrass, sorghum Sudan grass (sudex), teff, and buckwheat. Many of the nonleguminous cover crops are seeded where an increase in organic matter is prioritized over nitrogen benefit. In Kentucky's climate, some of the cover crops will overwinter while others will winter-kill, which means they will die over the course of the winter season. If the field with a cover crop is intended for an early cash crop the following year, a winter-killed cover crop will be desirable to aid in faster turnover and breakdown of the organic matter.

Examples of late summer or early fall seeded cover crops for winter-killing include oats and Austrian winter peas. They should be seeded between August and October 10.

Examples of mid to late fall-seeded cover crops for overwintering include cereal rye and crimson clover. They should be seeded between October 1 and November 10.

Figure 36. Nodulation on roots of a legume cover crop is from nitrogen fixation.

Figure 37. Oats and peas drilled in a fall field.

Figure 38. A worker fills the no-till grain drill with cover crop seed.

Table 9. Cover crop selection and seeding rates.[13]

Crop	*Type*	*Benefits*	*Singular Rate*	*Mixture Rate*
Austrian Winter Pea	Legume	Will winterkill in Zone 6	90 lbs/A	48 lbs/A
Cowpea	Legume	Adds nitrogen, good option for summer niche	100 lbs/A	60 lbs/A
Crimson Clover	Legume	Will overwinter in Zone 6, nice flowers in spring	25 lbs/A	10 lbs/A
Hairy Vetch	Legume	Adds nitrogen, attracts beneficials	25 lbs/A	20 lbs/A
Medium Red Clover	Legume	Will overwinter in Zone 6, versatile mixed in living mulches	25 lbs/A	10 lbs/A
Sunn Hemp	Legume	Adds nitrogen, fast growing, heavy biomass	55 lbs/A	30 lbs/A
Buckwheat	Non-legume	Fast growing, early flowering for pollinators	48 lbs/A	30 lbs/A
Cereal Rye	Non-legume	Heavy biomass, will overwinter in Zone 6	70 lbs/A	20 lbs/A
Japanese or German Millet	Non-legume	Versatile and economical early summer living mulch	70 lbs/A	20 lbs/A
Oats	Non-legume	Will winterkill in Zone 6	80 lbs/A	30 lbs/A
Peredovic Sunflower	Non-legume	Beautiful flowers attract pollinators	20 lbs/A	
Sorghum Sudan Grass	Non-legume	Heavy biomass	35 lbs/A	15 lbs/A
Teff	Non-legume	Can withstand multiple mowings, great for living mulch	15 lbs/A	15 lbs/A
Winter Barley	Non-legume	Early maturing, can use for succession	50 lbs/A	36 lbs/A

Examples of late spring- or summer-planted cover crops, suited for hot growing conditions only, include sorghum Sudan grass, sunn hemp, buckwheat, and teff. These crops are best seeded between May 1 and September 1.

Frequently, multiple species of cover crops are mixed in one planting to maximize the breadth of benefits, employing both leguminous and nonleguminous species. Examples of mixes include cowpea, buckwheat, and German millet for summer; oats, Austrian winter peas, and clover for late summer/early fall; and cereal rye, vetch, barley, and clover for late fall.

Cover crops are seeded using a Tye Pasture Pleaser no-till grain drill. Some succession cover crops can be sown direct into a previous year's residue without mowing in advance. Occasionally, discing will be required after mowing to break down residues for better cover crop seed-to-soil contact.

Living mulches are a cover crop integrated into a field setting during the active growth period of the cash crop. Most commonly, these crops are grown in between rows of plastic mulch beds. However, this is not the only application of living mulches. They can also be undersown along with a cash crop with reduced canopy coverage, like kale, in a bare-ground system. Mulches are effective at weed control for long-season crop fields and are easily managed by periodic mowing. Effective living mulches include:

- Teff sown between tomato and pepper beds
- Clover and cereal rye sown between fall garlic beds and other fields installed with plastic the previous fall
- Millet and clover for midsummer living mulches
- Crimson or red clover undersown for late fall brassicas

Figure 39. A BCS flail mower is used every one to two weeks to mow.

Figure 40. Teff in the aisles of the tomato field.

Figures 41 and 42. Drop spreaders suitable for undersowing and broadcasting living mulch seed between beds of plastic.

Living mulches are not planted in all production fields, primarily because of the timing for establishment and crop growth patterns. Quick-growing crops like early summer squash do not provide long enough windows of time for establishing the living mulch in early spring before the field is being mowed down. Vining crops like winter squash and melons will grow off the beds, making mowing living mulches impossible. Cultivation is generally preferred to living mulches for these crops, but the use of living mulches that are terminated early or straw mulch may be feasible. Other crops, like sweet potatoes, vine out so quickly that the plants themselves provide shade and outcompete weeds.

Living mulches are spread by use of a drop spreader pushed through the aisles or hand sown from a five-gallon bucket. To provide proper contact between the seed and soil, the soil is disturbed prior to spreading and/or lightly cultivated with a plastic cultivator, mini field cultivator, or scuffle hoe after sowing.

Cover crops are also used strategically for the benefit of the cash crops. Flowering cover crops act as refuge for beneficial insects and attract pollinators. In addition, buffer strips of buckwheat are routinely planted for these purposes, as well as for natural shading on summer lettuce. Planting buckwheat two to three weeks prior to lettuce on the east side blocks morning sun and keeps plants cool for a longer time, thereby helping to delay bolting.

Figure 43. Buckwheat on field edges attracts pollinators.

Figure 44. Grasses and buckwheat provide shade cover to summer lettuce.

Figure 45. Early establishment of a living mulch makes you-pick opportunities for CSA members more enjoyable and less muddy.

Fertility

Proper fertility is vital for a successful CSA and for growing high-quality crops. Vegetables that are nutrient deficient are stressed, may grow improperly or inconsistently, and are more susceptible to pest and disease pressures.

There are numerous sources of fertility, including cover crops, compost, soil organic matter (SOM), and granular or liquid fertilizer inputs. Soil tests will provide valuable information about the pools of fertility already in the soil.

Most fertilizer inputs contain the primary nutrients of nitrogen, phosphorus, and potassium, or N-P-K. In organic systems, fertility sources must be OMRI approved, which means all inputs that are used in agriculture have been independently reviewed by the Organic Materials Review Institute as meeting National Organic Program (NOP) standards. These inputs are biologically derived, frequently from either animal or plant sources; common examples include chicken litter, pork meal, kelp, or seaweed. At UK-CSA, fertilizer used is Nature Safe 10-0-8 Nitrogen and Potassium Fertilizer with Ocean Organics Kelp Extract. A phosphorus-free fertilizer is selected due to consistently adequate phosphorus levels in the soils. Nature Safe fertilizer reaches 60 to 65 percent mineralization after eight weeks.[14] Crops that are in production past eight weeks (56 days) are eligible to receive fertigation, but fertigation is only initiated for crops that mature in over 70 days. Fertigation is not made when crops will mature within two weeks of the 65 percent fertilizer mineralization date. Fertigation is a process of injecting a liquid fertilizer in the irrigation lines. Crops that benefit from fertigation at UK-CSA include head cabbages, tomatoes, peppers, eggplant, cauliflower, celery, and cantaloupe. See the Field Fertigation section in the UK-CSA SOP Manual for more information.

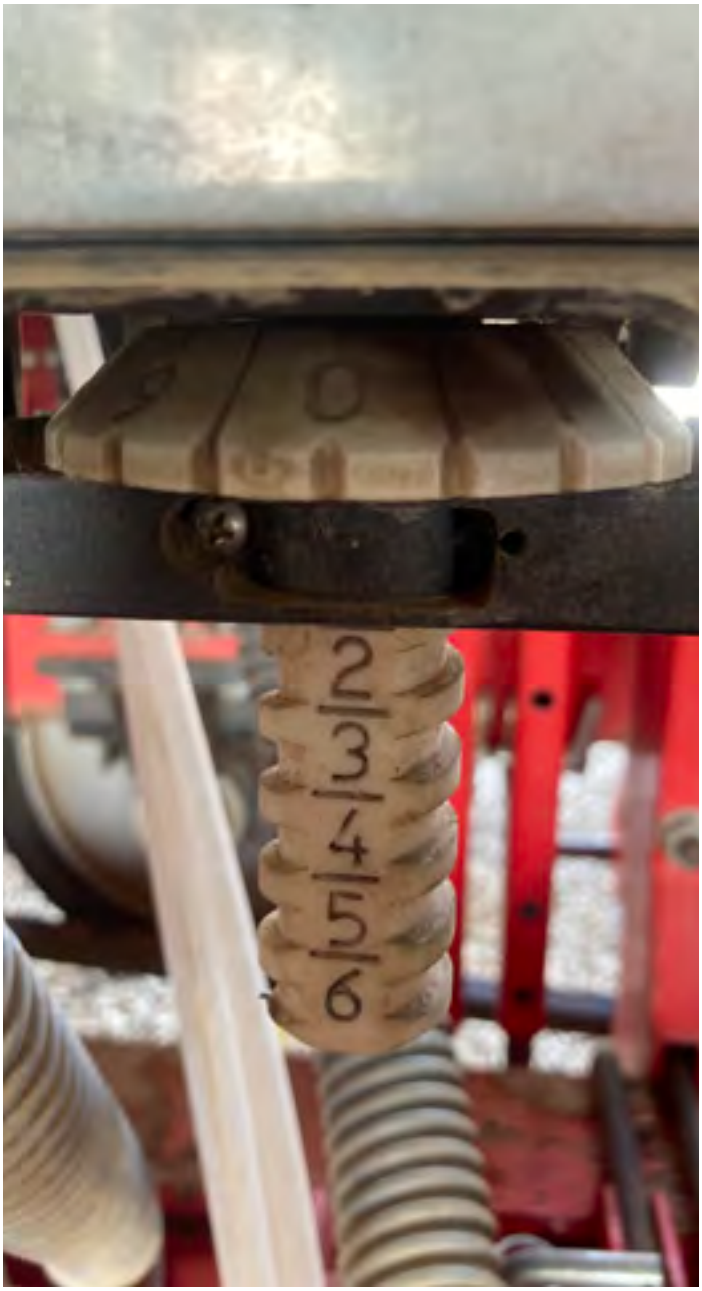


Figure 47. Fertilizer drop rate is adjusted by rotating the knob below the hopper.

Figure 46. Example of a fertilizer hopper on the back of an implement.

Figure 48. Control boxes are adjustable for fertilizer drop rate.

Implements that will side-dress or band fertilizer include the Mechanical Transplanter planter, MaterMacc vacuum seeders, Lilliston rolling cultivators, and the Rain-Flo plastic layer. The fertilizer application rate on each of these implements can be adjusted manually by changing the opening size on the fertilizer hoppers, by switching gears on ground-driven implements, or by making electronic adjustments with Servi-Speed control boxes. To determine fertilizer output, weigh how much fertilizer is dropped in 15-second intervals at each setting. With a constant speed on the tractor, output over a given distance can be determined and converted to pounds of nitrogen applied per acre. See Example 1 on next page.

To determine the desired rate of fertilizer to drop, the nitrogen credits from SOM, cover crops, and three-year historical fertilizer rates need to be considered in addition to the specific crop needs. See the Fertility Planner Workbook to determine target fertilizer rates by field and crop.

Example 1: Calculating Fertilizer Output with the Servi-Speed Control Box

Set control box to "5". In 15 seconds, the control box drops 1.2 pounds of fertilizer. The fertilizer is a 10-0-8 product, providing 0.12 pounds of nitrogen (N) in that time interval.

1.2 pounds/10 =
0.12 pounds N output in 15 seconds

The field is 300 feet long, or .057 miles long.

300 feet/5,280 feet per mile =
.057 miles

At medium and in third gear, the tractor used will travel 2.14 miles per hour, or .036 miles per minute.

2.14 miles/60 minutes per hour =
.036 miles per minute

The 300-foot bed will be traversed in 1.58 minutes.

.057 miles/.036 miles per minute =
1.58 minutes

In this time, 0.76 pounds of nitrogen will be dropped in the bed.

1.58 minutes × 60 seconds/minute =
94.8 seconds
94.8 seconds/15 seconds intervals =
6.32 intervals
6.32 intervals × 0.12 pounds nitrogen output per interval = 0.76 pounds N per bed.

Each bed is 300 feet long by three feet wide, or 900 square feet. Based on 43,560 square feet per acre, 48.4 beds of crops can fit on one acre.

43,560 square feet/900 square feet per bed =
48.4 beds per acre

This gives a drop rate of 36.7 pounds N per acre.

0.76 pounds N per bed × 48.4 beds per acre =
36.7 pounds N per acre

Irrigation

See the Irrigation Management section of the UK-CSA SOP Manual for complete details on determining irrigation event timing and duration.

Plant available water is another critical component to plant health. While Kentucky averages 40 to 53 inches of rainfall annually, summer precipitation only averages around 12 inches, so droughts and crop stress can occur.[15] Irrigation also has a direct correlation to consistent and predictable crop germination and yields. Crops are irrigated by overhead sprinklers or drip tape irrigation lines. Drip tape is a flat tube that trickles out water at even emitter spacings when filled. The water emerges from the top of the tape and spills over the sides. This irrigation method results in less evaporation and can result in 85 to 99 percent water uptake efficiency.[16]

UK-CSA irrigates from municipal sources only, and water usage monitoring is key. Drip irrigation is used across the farm, connected to Sun-Flow blue PVC water discharge hoses, or "layflat," by a custom-built manifold. The standard type of drip tape used is eight-mil Toro Aqua Traxx, with a six-inch emitter spacing. Two lines of drip tape are buried in each bare-ground bed, while only one line of drip tape is installed below the plastic mulch beds.

In intensive systems, drip lines are run on top of beds, but in the one-third-acre field plots, drip tape is buried using an Andros custom subsurface drip layer. The Andros subsurface drip layer can be adjusted for different depths. The goal is to keep the drip lines at the root zone for maximum efficiency. Burying the tape at a depth of roughly three inches, but no more than four inches, will be close enough to the root zone yet still low enough to cultivate on top of the soil with impunity to the drip lines. Occasionally, drip lines will be manually pulled out on top of beds or oscillating sprinkler heads will be temporarily installed to aid in quick germination. Drip lines that run subsurface can take a long time to percolate upwards when necessary to germinate seeds. Therefore, having a method of wetting the soil surface when a rainfall event is not in the forecast is imperative for some crops, like carrots. The alternative is to coordinate seedings with the weather forecast, e.g., to direct seed carrots right before an expected rainfall, and plant earlier when able.

At the end of a season, drip lines must be removed from the fields. A custom drip lifter will dig underneath the lines and loosen them. The lines can then be rolled up mechanically if loose, or they will have to be manually pulled up if they were not fully loosened by the lifter.

Figure 49. A worker checks the depth of the drip lines being installed with the Andros drip layer.

Figure 50. Sprinklers set up to reduce soil crusting and aid germination.

Figure 51. A drip lifter leaves the lines laying on top of the bed for easy pickup.

Weed Management

The plastic beds are cultivated on their shoulders using an IH Farmall 140 with a custom power-steering system; belly-mounted, straight-tooth cultivators; and small hilling discs for plastic bed-shoulder cultivation. Rear-mounted Danish S-tines cultivate the wheel tracks. This cultivator is referred to as the "plastic cultivator." For some crops, a living mulch is sown between the plastic beds for weed control. The living mulch is seeded after the beds are planted to minimize seed disturbance when using the water wheel setter and incorporated shallowly with one pass of the plastic cultivator.

Figure 52. Custom plastic cultivator.

An IH Farmall 140 with a custom power-steering system, belly-mounted Buddingh basket weeders, and rear-mounted spyder cultivators on Danish S-tines is used to shallowly cultivate bare-ground crops when they are very small. This implement is referred to simply as the "basket weeder" and is best used right after germination and until plants are either wider than two inches or taller than four inches. Crops that routinely get basket weeded include beets, carrots, spinach, lettuce mix, newly transplanted brassicas, green onions, cilantro, and dill. In addition, the basket weeder can be driven over freshly harvested, leafy green beds to disrupt the culled leaves and weed next to the plant stubble for a cleaner subsequent harvest.

Figure 53. Buddingh basket weeder.

A Kress Argus finger weeder is the second step in the cultivation process for the bare-ground system. Flexible "fingers" on the implement spin and allow for in-row cultivation. This capability allows for the most extensive cultivation and reduces the need for hand cultivation substantially. The fingers can be spaced closer together for more intensive in-row weeding or moved apart when plants are smaller and need to be handled more delicately. A smaller-scale finger weeder tool made by Terrateck can be pushed in high tunnels for similar cultivation.

Figure 54. Kress Argus finger weeder.

Figure 55. Terrateck double-wheel hoe with finger-weeding attachments.

The Lely Weeder, also called the "tine weeder," is a blind cultivation method; the operator does not see where the crops are in relation to the cultivators. The tines themselves ride over top of the crop. The tine weeder is useful for cultivating entire fields (e.g., between rows of drilled cover crop seed after the cover crop is established, or on potatoes, which can withstand the disturbance).

Smaller-scale tools include the Farmers Friend Pyroweeder, a 30-inch-wide, flame-weeding push tool with five burners. The flame weeder is used mostly for carrots, which require a long germination period. Flame weeding will not kill grasses, therefore successful implementation requires a field-specific knowledge of the weed species that present a challenge.

The tine weeding rake, part of the Eliot Coleman Signature Series, is a smaller-scale version of the tine weeder implement, at only 21 inches wide. This is most effective on the thread stage of plant growth before true leaf development, when weed seedlings are still small. This is best used on crops that have had a little time to adjust to their surroundings and won't be disturbed by having the rake pulled over top of them.

Figure 56. Lely Tine Weeder.

Figure 57. Flame weeding carrots with Farmers Friend Pyroweeder.

Figure 58. Tine rakes are used for thread-stage weeds.

Figure 59. Glaser wheel hoes cultivate wheel tracks, bed shoulders, and areas between plant rows.

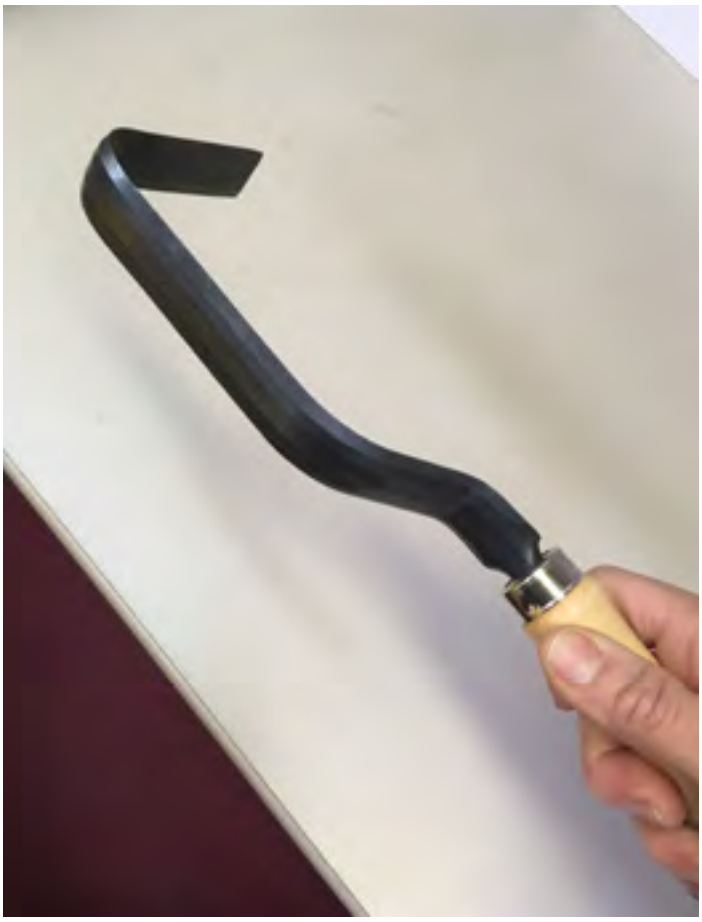



Figure 60. The hot bed weeder is a versatile precision hand-weeding tool.

Chop hoes are useful when getting rid of clumps of grass or weeds that have more enmeshed root systems. They can be used to slice the crops off at the surface. Hoes like the collinear hoe, stirrup (or "scuffle") hoe, torsion hoe, wire hoe, and Glaser wheel hoe are good for getting in tight spaces while remaining upright. These all disturb the top quarter inch of soil for minimal soil disruption and do not require a lot of force to operate.

Hand tools like the hot bed weeder, wire weeders, and Leonard Cape Cod weeders are best used for precision weeding and thinning on ground level and in row for small, seeded crops like carrots, cilantro, dill, and beets.

Cultivation on the farm is a regular occurrence. Weeding before a big rain is a priority, as a rainfall event can significantly add growth to small weeds. One rainfall event is enough to make weeds uncultivatable by the implements, which requires they be removed by chop hoes or even string trimmers. String trimmers, while not mentioned in this suite of cultivation tools, are used as a last resort when weeds have escaped cultivation to keep them from setting more seed in the field.

Integrated Pest Management

Pest and disease management is achieved by a multiplicity of practices. Cultural controls, physical controls, and chemical controls are all part of an integrated pest management (IPM) plan.

Cultural controls for reducing both insect and disease pressures include proper crop sanitation by removing diseased/affected plants; removing or mowing and tilling under old crop debris; planting flowering buffer zones that may act as trap crops or beneficial insect refuge; choosing disease resistant varieties of seeds; crop rotation; and introducing parasitic or predator insects to target specific crop insect pests.

A perennial herb and flower area serves as an overwintering shelter for beneficial insects as well as attracting more beneficials and pollinators when flowering. Buckwheat is a quick-flowering cover crop in summer, and whenever a field has space, a row of buckwheat is planted next to the crops to flower and attract beneficial insects throughout the growing season. A field edge buffer of sunflowers works well planted next to corn, due to similar growth patterns. They attract many pollinators and beneficial insects, and the sunflowers themselves are harvested and handed out in the CSA.

Beneficial insects like parasitic wasps, green lacewings, and lady beetles help to keep pest populations in check. Some pests that are controlled with parasitic and predator insects include aphids, moth eggs on cole crops, thrips, whiteflies, and leafhoppers. When released in a field or open area, there is no guarantee the insects will stay around. However, when released under insect netting, there is a better chance of control. Any beneficial insect release is made early, before the pests are an issue. For example, cantaloupe consistently suffers from aphid outbreaks on young plants. This pest is anticipated now on an annual basis. The strategy is to introduce green lacewing eggs every week for three weeks after planting under an insect net to keep aphid populations in check. This has been successful and reduced the need for an early chemical spray.

Cultural controls for diseases include bleaching tools during harvest and pruning, preventing irrigation water from splashing on leaves, or placing plants under cover in a high tunnel or haygrove structure to prevent rainsplash and disease spread.

Physical controls for pests deal primarily with insect exclusion. Netting is the best insect exclusion method. The netting used on-farm is ProtekNet insect barrier. On a low

Figure 61. Sunflower field edge next to corn.

Figure 62. Releasing green lacewing eggs under netting for aphid control on melons.

insect-pressure year, the yearly per-acre cost for netting crops is around 20 percent more expensive than the lowest cost spray program on a per-acre basis. On a high insect-pressure year, the yearly per-acre cost of using netting instead of spraying at a higher per-acre rate is around 20 percent less expensive. Therefore, in an average year, the per-acre annual cost of using netting versus spraying for the target pests is almost equal.

Row covering is another exclusion method, but most row covers provide thermal warming that may trigger premature plant bolting. The warming effect of row cover is sometimes preferable to aid in germination while also protecting the crop from insects. For example, row covers are frequently used over cucumbers that are direct seeded into plastic mulch beds. The cucumbers thrive in the warmth and are protected from cucumber beetles when they are small.

When netting is not used for insect exclusion, aluminized plastic mulch is integrated into the production system as an alternative pest management component. When netting is used, the reflective mulch is not needed.

Every covered crop is uncovered and cultivated at least two times during the crop's growth. In addition, some crops require pollinators. Pollinators need to be introduced when both male and female flowers are identified on the plant. Plants are scouted twice a week for flowers. Pollinators are introduced in one of three ways:

1. Pollinator boxes can be purchased and placed under the nets. This allows the nets to stay on but keeps the pollinators close to the target plants.
2. The nets can be removed entirely for two weeks.
3. The two field ends of the nets can be folded back and opened for two weeks, which keeps some pest coverage but allows for a controlled number of pollinators to find their way into the crops.

Option 2 is the simplest if the fields also need to be cultivated.

The crop netting protocols at UK-CSA indicate the correct covers for the major crop pests, but many more insects will be controlled for a given mesh size beyond those listed. See the Row Covering and Netting Crops section of the UK-CSA SOP Manual for instructions on covering crops.

Figure 63. Chemical applications made with a Penn's Creek Manufacturing 25-foot boom sprayer.

Table 10. Crop netting protocols.

Crops	*Target Pest to Exclude*	*Maximum Mesh Size*	*Net Weight per m²*	*Remove for Pollination?*
Brussels Sprouts, Broccoli, Cabbage, Cauliflower, Collards, Kale	Harlequin Bug	1.9 mm x .95 mm	60 gram	No
Arugula, Asian Greens, Baby Kale, Bok Choy, Eggplant, Napa Cabbage, Mustards, Turnips	Flea Beetle	.6 mm x .9 mm	47 gram	No
Cantaloupe, Pumpkin, Winter Squash	Cucumber Beetle, Squash Bug	1.9 mm x .95 mm	60 gram	Yes
Basil	Japanese Beetle	5 mm x 3 mm	55 gram	No
Blackberries, Raspberries	Spotted Wing Drosophilia	.85 mm x 1.4 mm	70 gram	No[1]

[1]While berries may benefit from pollinators, at UK-CSA these crops are part of a You-Pick operation, therefore bee boxes are not introduced into the picking areas. Pollination continues to be consistent even without introducing pollinators.

The last insect and disease control method is chemical. Some chemical controls are reliable in organic systems, but consideration is always given to the other methods prior to chemical control. In addition, chemicals are rotated to prevent resistance. Examples of insect chemical control include *Bacillus thuringiensis* (Bt) targeted to kill caterpillars like imported cabbage worm, armyworm, and corn earworm; spinosad as a lethal agent for Colorado potato beetle larvae; insecticidal soap for suffocating aphids; and kaolinite clay as a feeding deterrent for cucumber beetles.

Chemical controls are applied by various methods. In small plots or for isolated plants, a backpack sprayer is sufficient. For large acreage, a boom sprayer is used to go over tops of plants. Timing and coverage are critical. Some products degrade quickly in sunlight and must be applied after dark. Other products are only effective when contact is made or active feeding is taking place. Sprays are never to be done when wind speed is above 10 miles per hour. Applicators receive pesticide applicator licenses from the Kentucky Department of Agriculture.

Larger pests, including mammals like mice, voles, groundhogs, and rabbits, beset some areas at the farm. Deer are not an issue. An integrated approach for control includes exclusion, trapping, and attracting natural predators. Owl and bat boxes are one way to attract natural predators to keep mammalian pest populations down. Boxes are hung about 15 feet off the ground, facing east.

Figure 64. Barn owl box on tree near crop fields.

Harvest

Refer to Harvest Management section of the UK-CSA SOP Manual and the full Crop Handbook for detailed individual harvest guides.

During the CSA season, harvest occupies a large percentage of labor during the work week. The majority of harvest occurs the day before and the day of the CSA distribution, which at UK-CSA is on Wednesdays and Thursdays. However, crops dictate harvest practices, which may extend harvest to four or five days a week in peak times.

Harvest timing may shift to accommodate weather patterns. Some crops cannot be harvested in wet conditions. These include basil, beans, garlic, bulb onions, popcorn, potatoes, and sweet potatoes. At other times, crops can be harvested wet, when necessary, but should be avoided to reduce disease transmission. These crops include eggplant, tomatoes, peppers, cantaloupe, cucumbers, and squashes. If crops do get wet, they are dried with clean towels or fans are used to blow air over the bins to hasten drying out.

Some crops can be harvested when wet and may benefit from the moisture, as it will keep them cooler than when dry. These include leafy greens, broccoli, green onions, leeks, and sweet corn.[17]

Crops are cleaned as much as possible in the field to leave behind residue and soil rather than bringing it into the packing shed, where soil is destined to be washed off and trimmings are discarded. Peeling layers off some crops is one method of cleaning during harvest. This practice is useful for onions (green and bulb), garlic, leeks, head lettuce, bok choy, and cabbages. Another practice is to trim leafy material from tops, stem ends, and roots while in the field. Top-leaf trimming is done in the field for onions, garlic, leeks, kohlrabi, ginger, and turmeric, as well as carrots, beets, radishes, turnips, and rutabaga when greens are not used for bunching. Stem trimming is done in the field for bunched chard, collards, kale, basil, celery, asparagus, dill, and cilantro. Root trimming is done in the field for kohlrabi, onion, garlic, leeks, ginger, and turmeric.

Many vegetables will cause filled harvest bins to be quite heavy. Harvesting efficiency relies upon minimal handling of produce to reduce bruising, which can compromise storage life, and carrying heavy bins only the minimal distances necessary. The hydraulic conveyor eliminates carrying heavy bins of produce in many cases. When bins are heavy, two people can each carry a side to bring to the field edge or the wagon. All full bins are carried the shortest distance to the field's edge. The harvest wagon can circle the field to pick up all the bins. When bins are left in-row, such as in a summer squash field, workers can walk together in the same direction down the field rows and pass bins from right to left or left to right, until they are handed off to a worker on the harvest wagon.

Some crops are culled during harvest in the field. Factors that determine when to cull a crop include:

- presence of soft spots, rot, juicing, yellowing, or misshapen appearance (e.g., individual cucumbers with poor pollination, kale leaves with yellowing and browning edges, bruised tomatoes or tomatoes with splits that leak fluid, or white cauliflower with black spots of *Alternaria* on surface)
- presence of animal or bird feces on plant (e.g., bird droppings on a kale plant require the entire plant to be skipped and culled later)
- presence of insect infestation (e.g., many aphids on the underside of a kale leaf or a European corn borer hole and frass on the outside of a corn ear)
- the dropping of a crop on the ground that does not normally come in contact with the soil (e.g., tomato, pepper, or broccoli)

When crops are culled, they are removed from the field interior. They are placed in a cull bin and moved to the compost pile, or items are tossed into drive rows outside of the field. This ensures any potential pathogens on a culled crop do not spread readily to neighboring crops.

Figure 65. The harvest conveyor can carry filled buckets or individual crops.

Post-Harvest Handling and Storage

See the Packing Shed Management section of the UK-CSA SOP Manual for full wash line and packing shed operation details.

Figure 66. Interior of packing shed.

Figure 67. Cooler 1.

Figure 68. Cooler 2.

Figure 69. Cooler 3.

Figure 70. Harvested crops sit on pallets or roller conveyors.

Figure 71. Pallet jacks maneuver macro bins and stacked pallets in the packing shed.

Figure 72. Germicidal bleach solution is used for tool and surface disinfection.

Maintaining good crop quality requires care in harvesting as well as care in handling after harvest. Once the produce arrives at the packing shed, a few basic protocols are followed in keeping with food safety considerations. Crop bins are never set on the floor directly. They are always set atop a roller conveyor, a dolly, or on poly floor pallets. Four to five stacks of bins can be loaded on a 48-inch-by-40-inch floor pallet, or a single stack of bins can be loaded on a 15-inch-by-24-inch plastic minipallet. Floor pallets are maneuvered using a pallet jack, while the minipallets are moved using a custom hand truck with forks.

Product flow from doorway to cooler ensures no cross-contamination after washing. After washing, crops are always handled using clean and sanitized stainless-steel tables that are never contaminated with unwashed produce. If tables become dirty, they are sprayed down with water, scrubbed, and squeegeed to remove water. The tables are then sprayed with a final 10 percent bleach solution, which air dries, for disinfection.

Table 11. Crop storage environment selection guide.

Crop	*Temperature*	*Cooler*
Asparagus	32°F	1
Beets	32°F	1
Bok Choy	32°F	1
Broccoli	32°F	1
Brussels Sprouts	32°F	1
Cabbage	32°F	1
Cantaloupe	36°F	1
Carrots	32°F	1
Caulilflower	32°F	1
Celery	32°F	1
Chard	32°F	1
Cilantro	32°F	1
Collards	32°F	1
Dill	32°F	1
Fennel	32°F	1
Garlic, storage	32°F	1
Ginger, baby	32°F	1
Kale	32°F	1
Kohlrabi	32°F	1
Leeks	32°F	1
Lettuce	32°F	1
Onions	32°F	1
Parsnips	32°F	1
Peas	32°F	1
Radishes	32°F	1
Rhubarb	32°F	1
Rutabaga	32°F	1
Spinach	32°F	1
Sweet Corn	32°F	1
Strawberries	32°F	1
Turmeric, baby	32°F	1
Turnips	32°F	1

Crop	*Temperature*	*Cooler*
Beans	45°F	2
Cucumber	50°F	2
Eggplant	50°F	2
Peppers	50°F	2
Potatoes	50°F	2
Pumpkin	50°F-55°F	2
Summer Squash	41°F-50°F	2
Sweet Potato	55°F-60°F	2
Watermelon	50°F-70°F	2
Winter Squash	50°F-55°F	2
Tomatoes	55°F	3
Basil	Ambient	Pack Shed
Garlic, seed	Ambient	Pack Shed

Records of harvest amounts are essential for tracking crop yield and determining CSA amounts for each member. All harvest amounts, whether by count or by weight, are recorded prior to moving them into storage.

Optimal storage temperatures differ by crop (see **Crop Storage Environment Selection Guide**).[18] At UK-CSA, there are three cooler units that are adjusted to different temperatures. The main cooler is at 32°F to 34°F for all crops requiring a cold environment. The second cooler is kept at around 50°F for crops like potatoes, winter squash, summer squash, peppers, and eggplant. The third cooler is predominantly used for tomatoes and is kept at 55°F, but it is used for smaller amounts of summer squash, eggplant, winter squash, and potatoes when Cooler 2 is full of macro bins. Some crops, like garlic, do not require cold storage. Other crops, like sweet potatoes, are only moved into Cooler 2 for long-term storage. For full post-harvest handling and storage guidelines by crop, see the Crop Handbook.

Season Extension

See High Tunnel and Solar Greenhouse Management section of the UK-CSA SOP Manual for more information on using two of the four types of season extension structures.

While the main season of the CSA itself is late May to middle of October, the growing season can be extended by producing crops earlier in the spring and later into fall. The spring season relies on use of covered growing environments like high tunnels. Season extension efforts are focused on fall crops, with an eight-week fall program that runs from late October until late December. Fall CSA shares also rely upon storage crops and value-added items like dried garlic and turmeric, as well as fresh items from both field and tunnel. To keep crops alive through temperature fluctuations in late fall, winter, and early spring, row covers are a key tool for successful season extension.

Row covering is used primarily to protect crops from wind and cold temperatures; however, they will also exclude pests. During the heat of summer, row covers are not recommended for pest exclusion, as temperatures under the covering can rise quickly and trigger premature bolting of the plants. Row covers can be time-intensive to set up and cumbersome to take down for weed management.

A summary of crop winter hardiness for Kentucky zone 6b is given in the Winter Vegetable Killing Temperatures chart.[19] Referencing Table 12, row covers are chosen for crops based on crop location (field or protected in a high tunnel) and thermal protection needed. The thinnest covers of 0.55 ounces per square yard (Agribon 19) will have adequate protection against wind and light frosts, providing two to four degrees of thermal buffering. Midweight covers of 0.9 ounces per square yard (Agribon 30) can be used in a wide array of situations and will give four to six degrees of thermal buffering. The heavyweight covers of either 1.5 ounces per square yard (DeWitt Supreme) or 2.0 ounces per square yard (Agribon 70) should only be used sparingly for six to eight degrees of benefit, as they also block more than 50 to 70 percent of light transmission. Consult the Row Covering Protocols for Below Freezing Temperatures table. Tunnels on their own can provide two to three degrees of protection, but in a properly inflated, double-layered high tunnel with minimal wind gaps, there may be closer to five degrees of buffering.

Heavier row covers of 1.5 ounces per square yard or more should always be used with hoop supports. Lighter covers of 0.55 to 0.90 ounces per square yard can float on top of plants inside tunnels, but in the field, hoops will keep the covers from touching the leaves, where points of contact can cause freeze damage.

Row covers need to be weighted on all four sides when placed over crops in the field. See the Row Covering and Netting Crops section of the UK-CSA SOP Manual for more information.

Table 12. Winter vegetable killing temperatures. Adapted from Pam Dawling, Storage Vegetables for Off-Season Sales, 2017 Slideshare

Outside Temperature Lows	*Crops Affected*
35°F	Basil
32°F	Beans, Cauliflower heads, Corn, Cucumbers, Eggplant, Melons, Okra, Peppers, Potato vines, Squash vines, Sweet Potato vines, Tomatoes
27°F	Fresh Cabbage
25°F	Napa Cabage, Dill, Fennel, Mustards and Asian Greens (Bok Choy, Tokyo Bekana, Mizuna included), Green Onions
22°F	Arugula, Lettuce
20°F	Beets, Broccoli heads, Some Brussels Sprouts, Storage Cabbage, Celery, Parsley, Radishes, Rutabagas, Turnips
15°F	Russian Kale, Kohlrabi, Chard, Cilantro
12°F	Some Beets, Carrots, Collards, Garlic Tops (large), Summer Leeks, Winter Radish
10°F	Sprouting Broccoli, Brussels Sprouts, Some Collards, Tatsoi, Savoy Spinach
5°F	Garlic Tops (small), Some Kale and Leeks
0°F	Chives, Garlic, Vates Kale, Green Onions (Everygreen Hardy White), Parsnips, Spinach

Table 13. Row covering protocols for below freezing temperatures.

	FIELD		TUNNEL	
Crops	Outside Temperature	Row Cover Weight	Outside Temperature	Row Cover Weight
Arugula	22°F	Light/Mid	20°F	Light/Mid
Asian Greens	25°F	Light/Mid	22°F	Light/Mid
Beets	20°F	Light/Mid	18°F	Light/Mid
Bok Choy	25°F	Light/Mid	22°F	Light/Mid
Broccoli	20°F	Light/Mid	N/A	
Brussels Sprouts	10°F	Heavy	N/A	
Brussels Sprouts	20°F	Light/Mid	N/A	
Carrots	12°F	Light/Mid	10°F	Light/Mid
Celery	20°F	Light/Mid	18°F	Light/Mid
Chard	15°F	Light/Mid	12°F	Light/Mid
Cilantro	15°F	Light/Mid	12°F	Light/Mid
Collards	12°F	Light/Mid	10°F	Light/Mid
Green Onions, Evergreen Hardy White	10°F	Light/Mid	0°F	Light/Mid
Green Onions, Parade	25°F	Light/Mid	22°F	Light/Mid
Kale, Other	15°F	Light/Mid	12°F	Light/Mid
Kale, Vates Blue Scotch	10°F	Light/Mid	0°F	Light/Mid
Lettuce	22°F	Light/Mid	20°F	Light/Mid
Napa Cabbage	25°F	Light/Mid	22°F	Light/Mid
Peppers	32°F	Light/Mid	30°F	Light/Mid
Potatoes	32°F	Light/Mid	N/A	
Radish, Winter	12°F	Light/Mid	10°F	Light/Mid
Radishes	20°F	Light/Mid	18°F	Light/Mid
Rutabaga	20°F	Light/Mid	18°F	Light/Mid
Spinach	10°F	Light/Mid	8°F	Light/Mid
Strawberries	20°F	Light/Mid	18°F	Light/Mid
Strawberries	15°F	Heavy or Double	12°F	Heavy or Double
Tomatoes	32°F	Light/Mid	30°F	Light/Mid
Turnips	20F	Light/Mid	18F	Light/Mid

Season extension can be managed through different growing environments, in addition to utilizing row covers in field production. There are four types of covered growing environments at UK-CSA that have been used. High tunnels are the standard season extension environment. The high tunnels are walled on all four sides and have a gothic arch roof. These structures are vented by opening end wall doors as well as raising and lowering sidewall curtains. Three of the high tunnels in use can also be moved along rails to allow for crop rotation and cover cropping, as well as managing optimal crop growth windows. Each tunnel is 30 feet by 72 feet.

Example of optimizing crops with movable tunnels: Winter greens can be grown inside a tunnel, and as spring temperatures warm, the tunnel can be moved off the winter greens, which are frost tolerant. The tunnel then covers a new plot for early spring tomatoes.

Figure 73. High tunnel structure.

Caterpillar tunnels are a smaller version of high tunnels. These structures use a single sheet of plastic to cover sides and ends. Roping holds the plastic in place. Ends are tapered into a cone shape and secured at ground level; they can also be modified with doors. Sides can be raised and lowered manually by adjusting the plastic height behind the roping. Caterpillar tunnels are usually shorter in length, narrower, and not as tall as a true high tunnel. They also have presented challenges in windy conditions and are ideally situated in a north-south orientation to mitigate winter wind damage originating most strongly from the south.

Figure 74. Caterpillar tunnel structure.

Figure 75. Haygrove structures.

Haygroves also use roping over a single sheet of plastic, like caterpillar tunnels, but they have no end walls and no side walls. The plastic is secured on top of the plot as a roof-only structure. This structure will not help with season extension unless sidewalls and endwalls are added. This structure cannot withstand snow loads and has collapsed during winter storms. The plastic can be shed to prevent snow-load damage but often cannot be reused after it is removed. The primary utility of a haygrove is protection from rainfall for crops that are more susceptible to water-dispersed pathogens, like peppers and tomatoes.

The fourth covered structure at UK-CSA is a solar greenhouse, also known as a "deep winter" or "Chinese" greenhouse because of its widespread use in Asia. This greenhouse is an experimental design utilizing passive solar energy to heat the growing environment. The north side of the structure contains two types of walls; one half of the wall is sand held in by panels of corrugated metal and wood framing, while the other half of the wall is comprised of recycled pickle barrels filled with water and painted black. The sand provides greater thermal mass, giving higher temperature peaks, but it does poorly in keeping the heat overnight. The water-barrel wall does a better job of reducing heat spikes during the day and maintaining more heat during low-temperature nights. The solar house is vented through end-wall doors and one curtain to the south. The air temperatures in this growing environment are difficult to manage, and crops that are sensitive to bolting will not do well here in the off-season. The primary use of the solar greenhouse is to grow tropical crops in summer, like ginger and turmeric.

Figure 76. Solar greenhouse planted in ginger and turmeric.

CSA Labor

Labor management at UK-CSA differs from most commercial farms. Due to the focus on education and extension, students are involved with production at intermittent times throughout the year. However, the CSA is not a student-run enterprise; it requires five full-time equivalent (FTE) staff members to manage the program. Only two FTE staff are kept during the winter, while during the main season, several additional part-time staff are hired to help with harvest days. The normal summer harvest crew amounts to six to 10 people at peak times.

Job training as well as continuing education are vital for all staff and for maintaining efficiency. All workers are trained on food safety, worker safety, cash handling, tractor safety, and packing shed management. The breadth of experience is valuable at the outset to ensure multiple people are proficient in various tasks and able to work independently if needed. After staff have been at UK-CSA beyond a season, developing a greater depth to their skillset and knowledge is encouraged through continuing education and greater focus on specific production elements as part of their staff responsibilities.

CSA Membership

Member management encompasses several areas. Terms and conditions for CSA membership are revised annually. Terms and conditions are important in preparing members for what it means to take part in a CSA, as well as logistics covering payments, missed pick-up policies, and you-pick protocols. CSA benefits and risks are outlined in the terms and conditions. Reading and agreeing to terms and conditions is required prior to CSA registration. Members also receive a handbook at the start of the season. The handbook covers best practices for storing vegetables and shelf life for different crops. Tips on preservation are also included. Engaging members not only during the season but also on the off-season is part of the marketing strategy to increase retention. Engagement occurs through blog posts, weekly or biweekly emails with farm updates and farm stand sale announcements, and frequent social media posts on Instagram or Facebook. Members are also valued for their input, which is solicited at the end of the season through a member-only survey.

At the conclusion of every CSA season, the CSA box value is tabulated based on retail market price. CSA membership is not advertised as discounted produce; however, CSA membership provides added value that members would not receive when buying items a la carte. In addition, members benefit from the surpluses on-farm, which help to offset any risks. Every year, the final dollar value of the share varies, but overall, it has consistently met or exceeded the up-front purchase share price. Box values for the season are averaged. There are certain weeks when the value may be lower than the weekly costs, but this is also countered by bountiful midsummer weeks when the value is much higher than base cost. This variability is inherent based on seasonality of produce and availability of high-dollar-value items. Looking at the weekly box value average, keeping it at no more than 15 percent above retail price is the target at UK-CSA.

In addition to the value of the share itself, CSA members experience added value to their shares through the community aspects of CSA. Members receive electronic newsletters with farm news and recipes tailored for that week's share contents. On-farm you-pick is a highlight for many members. At UK-CSA, a third of an acre is dedicated for you-pick options for members and their families. Crops in you-pick include those that are less desirable to be hand-harvested by the crew (e.g., cherry tomatoes and okra), as well as crops that are desirable for members and have long production. The you-pick crop options include blackberries, raspberries, cherry tomatoes, hot peppers, specialty peppers, tomatillos, green beans, kale, okra, flowers, and herbs. A final way for community building occurs through on-farm events, like potlucks.

Figure 77. You-pick field is a benefit for CSA members.

CSA Marketing

Due to the connection to the University of Kentucky, the UK-CSA program is not advertised outside of the institution. All of the CSA members are current UK staff, students, faculty or alumni, or they are connected to the program through one of the former. UK-CSA is one of the five founding farms to participate in the Kentucky Farm Share Coalition's voucher program in partnership with the University of Kentucky's Health and Wellness group. Since 2015, current employees on a UK health care plan are eligible to receive $200 as a taxable benefit to apply to the organic CSA program of their choice. Preliminary results indicate improved health outcomes for participants, particularly for new CSA members who were in an at-risk health bracket.[20] In addition, CSA members reduced doctor visits and pharmacy expenditures as a result of CSA participation. There have been over 2,585 vouchers dispersed through UK Health and Wellness from 2016 through 2021, and 645 of these vouchers were applied to the UK-CSA program.

Customer retention is a challenge for all CSA producers. Barriers to retention include educating consumers adequately in preparation for membership in a CSA, market-driven choices of farms, and changes in members' life circumstances. Retention percentages have varied year to year at UK-CSA in part due to changes in membership numbers. The current member retention percentage at UK-CSA is 60.4 percent. In addition, 10 percent of current members are non-consecutive repeat subscribers, having let their membership lapse for one or more gap years before joining again. Therefore, repeat subscribers of UK-CSA from both consecutive and non-consecutive years make up 70.4 percent of the total membership. As a point of comparison, a study in 2015 of more than 300 CSA farms in the Midwest found average retention rate to be 46.1 percent.[21] A second study of 80 CSA programs in California found a mean retention rate of 62.9 percent.[22]

Certifications

USDA GAP

In 2015, UK-CSA began to sell wholesale products to UK Dining, and later to Aramark as the food service provider for the University of Kentucky. As a part of this process, a few crops grown at the Organic Farming Unit underwent USDA third-party Good Agricultural Practices (GAP) audit and certification. To become GAP certified, upgrades were made to OFU facilities and harvest procedures, including the addition of a harvest conveyor, installation of a floor trench drain in the packing shed, installation of battens on exterior walls, and the addition of doors to every entrance of the uninsulated pack shed. A significant part of this process was also the development of a comprehensive Food Safety Manual for the entire OFU. The total investment of materials and estimated labor costs for the GAP upgrades amounted to $21,155.26, funded in part externally by the Food Connection at UK. UK-CSA passed the GAP audit in 2015, 2016, and 2018. After trialing wholesale market channels, the UK-CSA shifted focus solely onto CSA marketing as a better return on investment. However, the food safety guidelines are still followed as outlined in the UK-CSA Food Safety Manual.

USDA Organic

While some GAP-specific recordkeeping is no longer needed, the UK-CSA maintains thorough records in keeping with organic certification. A full Organic System Plan (OSP) is submitted annually. Accompanying documents include records of seed and live plant material orders and associated organic certificates, planting records, field plans, field activities, compost and manure applications, soil tests, harvest records, shared equipment usage and cleaning records, pesticide spray logs, and lists of all inputs. Certification is handled through the Kentucky Department of Agriculture (KDA) and inspections are conducted annually.

Beyond the Farm Gate

UK-CSA is atypical in the farming landscape; it exists within a land-grant institution, which means the university's tripartite mission of extension, education, and research infuses the work around the farm. While running a successful CSA program is one outcome of this work, the focus is around elevating the broader farming community, educating consumers, and investing in the next generation of producers, particularly in sustainable and organic production. UK-CSA welcomes thousands of visitors to the farm each year: students who learn from hands-on activities, farmers for field days, and community members for tours. In addition, CSA members and their families also occasionally volunteer their time in the fields with the CSA staff. Finally, UK-CSA also gives back by donating extra and "seconds" produce to a non-profit organization called GleanKY for redistribution to food banks and shelters.

How the Use the Handbook

The Crop Handbook contains profiles for most of the crops grown at UK-CSA. Some crops are grouped together due to similarity in management. Each profile follows a similar format.

Crop Name.

The crop featured on the profile is listed in the header at the top. Below the crop name, the crop family is listed.

Varieties.

The crop profiles offer an overview of varieties grown successfully at UK-CSA. Comments on varieties and their planned days to maturity are provided.

Greenhouse Production.

Those crops grown in a greenhouse will include their seeding dates, tray size, potting-up requirements, and the number of weeks required to grow in their trays. If the crop is direct seeded, this section will be omitted.

Field Preparations.

Field preparations include any specific considerations addressed before the plants go in the ground. All bare-ground plants will have two lines of subsurface drip tape installed prior to planting and will be cultivated with the stale seedbed cultivator three times prior to planting. With crops grown on plastic, the type of plastic mulch used is indicated. All plasticulture crops are grown with one line of drip tape per bed, and any fertilizer required will be applied at the time of plastic mulch installation, using Nature Safe 10–0–8. Any crop grown outside of the standard two systems will be discussed in further detail.

Direct Seeding.

All direct-seeded crops are seeded on bare ground or in biointensive areas. Earliest and latest seeding dates are given. The settings for the MaterMacc vacuum seeder or the Jang push seeder are given. Fertilizer requirements are noted, as Nature Safe 10–0–8 will be applied at seeding for all bare-ground production crops.

Transplanting.

Any crop grown as a transplant will either be planted on bare ground with the Mechanical Transplanter 5000, planted on plastic with the Rain-Flo water wheel setter, or hand-planted. Equipment settings, plant spacing, and earliest and latest planting dates are noted. The fertilizer requirements using Nature Safe 10–0–8 are included for any plant in bare-ground production.

Cultural Practices.

This section considers the variations in management that make each crop unique. Specific weed problems, pest issues, or disease pressures are addressed. Netting or covering requirements are discussed, along with any protocols that diverge from normal production. Any changes to the standard weed-control methods are also included.

Harvest.

Individual profiles discuss indicators for crop readiness, tools to use for harvest, harvest techniques, and any other pertinent details.

Yield.

These numbers are measured per row foot, averaged from the prior year's average and current year's actual harvest data. In addition, amounts of each crop that are handed out to CSA members are also noted, along with frequency.

Post-harvest Handling.

This section discusses how all crops are brought in from the field and handled in the packing shed. This includes the wash line(s) they require, sorting, and packing protocols.

Storage.

All crops have optimal temperatures to prevent any cold damage. Best storage environment and estimated shelf life is included in this section.

CROP HANDBOOK: ASPARAGUS

Family: *Asparagaceae*

Varieties

Asparagus varieties grown are Millennium, Jersey Supreme, and Purple Passion.

Field Preparations

Asparagus is planted in bare ground, one row per bed.

Transplanting

Asparagus crowns are hand-planted in early April. Beds are spaced four feet apart on center. Trenches are made with furrowers on the back of a tractor-mounted toolbar. Each trench is around 12 inches wide, and crowns are planted at an eight-inch depth. In-row spacing between crowns is 12 inches, therefore 100 crowns are planted in each row in the plot, which is 100 feet long. The roots of the crowns are split and spread in two directions inside furrow. Crowns are covered with only two to three inches of soil at planting. Crowns are then covered gradually on a weekly basis as they grow, until the entire furrow is filled in with soil.

Fertility requirement is 150 pounds of nitrogen per acre during establishment. Fertilizer is split with 75 pounds of nitrogen per acre added in the furrow at planting, and the remaining 75 pounds of nitrogen per acre added after spear emergence. Compost at 10 tons per acre rate is added in the furrows.

Furrows dug eight inches deep by tractor.

Asparagus crowns are kept moist until planting.

Crowns are spaced out every 12 inches. Roots are spread out in two directions.

CROP HANDBOOK: ASPARAGUS

Family: *Asparagaceae*

Cultural Practices

After planting, woven landscape fabric three feet wide is installed between the rows, leaving around 12 to 18 inches in width for the asparagus row to send spears up and expand growth. Wood chip mulch is placed on top of the row for weed control.

The asparagus plot can be mowed once in late summer, in August, to get rid of weeds and any weed seed heads. The plants will rebound and grow up again before overwintering.

In the winter, around late March, all asparagus residue is mowed to the ground. The woven landscape fabric is removed one side at a time and pulled back for flail mowing with the BCS walk-behind tractor. The fabric is reinstalled with sod staples, and then the opposite side is pulled back to mow the next row.

Asparagus can be mowed once in late summer for weed control.

Beds are mulched in-row, and landscape fabric is installed between rows.

Fabric is folded back so that overwintered ferns and fronds can be flail mowed.

CROP HANDBOOK: ASPARAGUS

Family: *Asparagaceae*

Asparagus spears are harvested when they are eight to 10 inches tall.

Asparagus spears are harvested into bins or buckets.

Asparagus is fertilized after the harvest period annually, requiring 50 to 75 pounds of nitrogen per acre. When applying compost, four pounds of nitrogen per acre can be subtracted from the annual fertilizer needs for every ton of compost applied. With a 10-ton-per-acre compost application rate, only 10 to 35 pounds of nitrogen per acre will be needed each year after establishment.

Hand-weeding and hoeing is needed several times during the growing season after spring harvest.

Harvest

No asparagus spears are harvested the first year they are planted. In the second year, spears are harvested for two weeks. In year three, harvest lasts for four weeks. In all years following, harvest continues for six to eight weeks.

Spears are harvested when eight to 10 inches tall and should have tight spear heads. A serrated knife is used to cut individual spears at the base. The knife should not dig into the soil so as not to damage any new spears beginning to emerge. Spears are placed in red harvest buckets until brought to the packing shed.

When in season, spears are harvested daily, if possible. Harvesting every other day is also sufficient.

Yield

As of 2021, asparagus is still in the establishment phase and yield has not been tracked.

Asparagus is a spring item only, as it matures prior to the start of the main CSA season.

Post-harvest Handling

Asparagus that is harvested in red buckets is either dunked or washed on the rinse conveyor. Spears stand upright in clean red buckets and the buckets are set inside larger tote containers with one inch of water at the base to keep cut ends fresh. Spears are banded in one pound bundles with a rubber band tied about four inches above the cut ends. Ends are aligned even if the spear tips are slightly different heights. Purple and green varieties can be mixed. Bundles are placed into smaller containers or five-gallon buckets with one inch of water to transport.

CROP HANDBOOK: ASPARAGUS

Family: *Asparagaceae*

Spears are bundled and then placed upright in containers with an inch of water at base.

Storage

Asparagus is stored at 32°F. Plastic covers are placed over bins for moisture retention.

Asparagus can last two to three weeks in the cooler.

One-pound asparagus bunch.

CROP HANDBOOK: BEANS

Family: *Fabaceae*

Varieties

Green bean varieties for mechanical harvest include Momentum, Caprice, Greenback, and Cosmos. Varieties are chosen for a one-time harvest, producing a concentrated pod set suitable for harvesting with the Pixall bean harvester. Caprice does not set beans well in heat, so this variety is the first variety seeded in cooler conditions.

Specialty varieties include Roma II, Navajo, or Furano (flat pod); Carson (yellow wax); and Tohya or Chiba Green (edamame).

Productive varieties for you-pick that do not require a concentrated pod set include Jade and Provider.

Green beans mature in 53 to 56 days from seeding.

Dry beans are not grown due to their labor-intensive post-harvest handling requirements of winnowing. In addition, dry beans are not easily harvested mechanically, as dry pods will shatter. Dry beans may be included in the you-pick field.

Direct Seeding

Green beans are seeded using the MaterMacc vacuum seeder. Seed plate 72, 4.5 is used, and in-row spacing is two inches, which on the MaterMacc are sprockets 22-22. *Note: These sprockets are not the same if using the MaterMacc VegiMacc vacuum seeder. The MaterMacc VegiMacc can be used as a backup, but beans seeds can become clogged due to their large size.*

The MaterMacc seeder is driven no faster than 2.0 miles per hour to prevent clogging. The chutes from the bean hoppers are monitored to ensure the beans are flowing freely.

Earliest recommended seeding is April 25, and latest is July 25. Seeding date is calculated to correspond to a Tuesday or Wednesday harvest prior to the CSA distribution date on Thursday.

5,000 seeds are allotted per bed, or 2,500 per row.

Beans on the plant ready to harvest.

Beans are direct seeded with the larger of the two MaterMacc vacuum seeders.

CROP HANDBOOK: BEANS

Family: *Fabaceae*

Field Preparations

Beans are grown on the bare-ground system. No fertilizer inputs are required for beans.

Cultural Practices

Plants are monitored for Mexican bean beetle larvae and adults, and leafhoppers. In order to disrupt pest patterns, each bean planting is seeded into its own field, rather than side by side. Bean plantings are moved around the farm and isolated geographically for maximum pest disruption. Timely sprays of Pyganic, Entrust, or Neem can knock back Mexican bean beetle larvae, but contact is required for efficacy. All bean plantings are situated on the outer edge of the field to accommodate harvesting with the Pixall bean harvester.

Beans are basket weeded after germination, and finger weeded until plants begin to flop over and send out tendrils. Beans are not aggressively finger weeded, as this causes too much soil to build up around the plant stems. Immediately prior to harvest, field edges are mowed and workers hand-pull or scuffle hoe any larger weeds by walking the rows.

Harvest

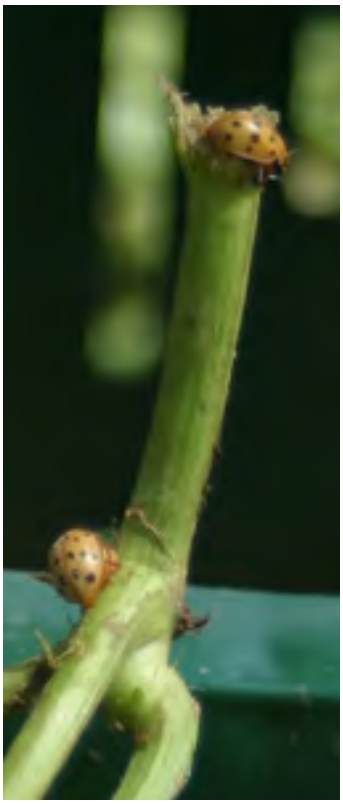
All beans other than you-pick varieties are harvested using the Pixall BH100 Bean Harvester. If beans are planted on the eastern edge of a field, the field is entered with the harvester from the north. If beans are planted on the western edge of a field, the field is entered with the harvester from the south.

Beans must be dry before harvest. Ideally, harvest begins around 10 or 11 a.m., after the morning dew has evaporated.

Two people are required to harvest beans. The driver runs the Pixall harvester on the Kubota 9540 or the Kubota 5030. The 9540 is run in the snail 5 gear and 540 PTO. The 5030 is run in the medium gear range and 540 PTO. Maximum ground speed is 0.75–1 mph. Faster speeds cause pod breakage. Ear plugs are worn when operating the Pixall harvester.

The second worker drives a truck to the field with stacks of dark green or blue bins to catch the beans. The truck is parked out of the way of the harvester in the opposite drive row or at field ends past the bean rows themselves. The worker sets up eight bins on the back of the harvester: one under each of the two chutes, and six stacked upside down under the fan blower. The worker rides on the machine and monitors the harvest.

Beans are seeded two inches apart, and about one half-inch deep. This is how they would look under the soil surface.



Mexican bean beetle adults. In larval stage, they are bright yellow.

After germinating, beans are basket weeded.

Family: *Fabaceae*

The Pixall BH100 Bean Harvester captures bean plants in a pair of tines that funnel plants into the picking reel.

The second worker monitors beans coming out of the chute and switches the chute when one side is full.

The front tines of the harvester guide the bean plants into the rotating picking reel. The bean stem should be within one inch of the outside tine. The hydraulics raise and lower the tines. The tines themselves should barely scrape the soil surface or ride along just above the soil surface. The worker on the back monitors the chutes for any rocks, debris, or soil. If any soil comes into the bins, the worker gives the stop hand signal to the driver and indicates to move the machine up higher. When harvest resumes, the worker on the back switches the chute once field soil is no longer being pulled into bins, to keep the next beans from mixing with those in the soiled bin. Bins weighed down with soil are set aside for sorting and cleaning in the packing shed.

If plants or soil is exceedingly wet as a result of a recent rain, the machine will not operate successfully. In these situations, green beans must be harvested by hand or not at all. Workers pull the entire plants and strip individual pods off the stems into red buckets. Two red buckets are nested in each other at an offset to close the side gaps, preventing harvested beans from falling out the sides. Workers are discouraged from sitting on buckets during harvest, as this will slow down the process.

Only stems remain in the field after harvest.

CROP HANDBOOK: BEANS

Family: *Fabaceae*

When rocks or debris come into the harvest bin, as at left, the worker in the field or on the back of the machine gives the driver the sign for "stop" with a closed fist, shown at right.

Clean beans ready to bag. Beans may still have smaller stems attached.

Flat pod beans, also referred to as "Roma" type.

Bagged beans for CSA share. Bag top is twisted or folded down for packing.

Yield

Bush green beans can yield 100 pounds per 300-foot bed, or 0.25 to 0.35 pounds per row foot.

Since acquiring the mechanical harvester, green beans are now included in CSA shares four to six times a season. For at least one or two weeks, the shares will include a specialty bean, like flat pod, yellow wax, or edamame. Each share distribution includes approximately one and a half to two pounds of fresh green beans. Flat pod beans are heavier and the share amount may be closer to two to two and a half pounds of flat pod beans.

Post-harvest Handling

All beans are weighed as they come into the packing shed. Any beans in bins with dirt are sorted into a clean, dark green bin before being weighed. Washing beans is avoided as it compromises storage life. On the rare occasion that beans become excessively muddy during a wet harvest, the barrel washer is used to rinse beans. Beans are spun in the Greens Machine salad spinner to remove as much moisture as possible. Spun beans are placed in dark-green bins and allowed to drip-dry overnight before bagging. Beans are not bagged more than one day in advance if washed.

Some small bean stems are acceptable when bagged, as not every bean is plucked cleanly from the plant. The larger plant stems and debris (rocks or leaf matter) are pulled out before bagging beans. Some beans will be broken. Large broken beans are kept, while small bean pieces are discarded. Beans with excessive scarring from bean beetle feeding damage are also discarded, while a small scar is tolerated. The bean-sorting process inside the pack shed will take four to six workers working for two hours at a minimum. When yield is high, beans can be sorted more quickly by focusing on the larger, cleaner beans to put in the bags.

Green beans are bagged in clear plastic bags, and tops are twisted or folded over to close. Bags are stacked in dark-green bins in two to three layers, with seven to 10 bags in each layer. Weightier bags will result in fewer bags per bin.

Storage

Beans are optimally stored in the cooler at 40°F to 45°F, but they can be stored at 32°F to 34°F without chill injury. When beans are loose, plastic pallet covers are not pulled over the bins until the end of the day to minimize field heat condensation. When beans are already bagged, no plastic covers are needed over the bins. Beans are distributed within one to two days.

CROP HANDBOOK: BEET AND SWISS CHARD

Family: *Amaranthaceae*

Varieties

Beet varieties grown include Red Ace, Red Cloud, Cylindra, Moneta, Chioggia Guardsmark, and Touchstone Gold.

Beets mature in 45 to 55 days from direct seed.

Swiss chard varieties grown include Bright Lights in the main season, and Peppermint in winter.

Swiss chard matures in 55 to 60 days for bunching size from direct seed.

Greenhouse Production

Both beets and chard are seldom grown as transplants. However, for biointensive plantings, they are seeded in 162-cell Winstrip trays four weeks prior to target transplant date.

Field Preparations

Both beets and chard are grown on bare ground. Both can be grown intensively in fields or tunnels.

Direct Seeding

Chard is seeded at four-inch in-row spacing. This spacing is for larger, bunching sized leaves.

Beets are direct seeded at in-row spacing of 1.5 inches. They are thinned to three inches after germination.

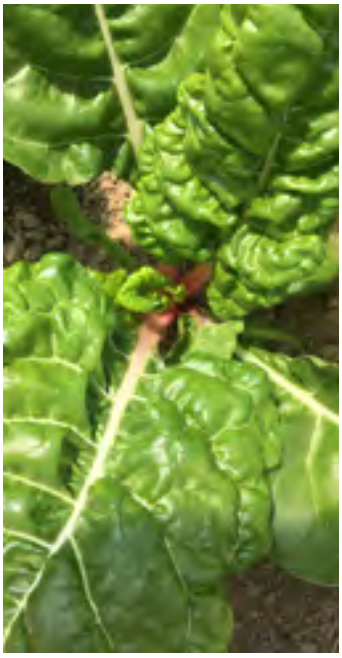
MaterMacc VegiMacc plate 96, 2.5 is used for beets, and plate 36, 2.5 for chard. For 1.5-inch spacing on beets, sprockets used are 22-22. For 3.9 inches on chard, sprockets 22-21 are used.

In intensive systems, beets and chard are grown with three rows per bed. Jang push seeder is used with seed roller LJ-12, or the crops are hand-transplanted after being grown in the greenhouse.

Beets require 50 pounds of nitrogen per acre, while Swiss chard requires 125 pounds of nitrogen per acre. All fertilizer is banded at time of seeding.

Earliest seeding date recommended in the field for chard is March 20, and latest is July 15. Beets have a wider planting window: March 15 at the earliest and August 10 at the latest.

Cylindra beets pop out of the ground when they are harvest ready.



Peppermint chard grown in a tunnel.

Beets being hand-planted in a bio-intensive plot.

Swiss chard leaves at full size for bunching.

CROP HANDBOOK: BEET AND SWISS CHARD

Family: *Amaranthaceae*

Cultural Practices

Neither chard nor beets have many troublesome pests. Cercospora leaf spot is common for beet leaves. This is mostly cosmetic damage. Roots are sometimes attacked by aphids. Flea beetles may also be an issue at certain times. Chard is more vulnerable to grasshoppers, which can take large bites out of leaves.

Beets and chard are cultivated with the basket weeder and finger weeder, before beets have enlarged. Beets are also hand-weeded in order to thin them to a wider spacing. Thinning is optimally done soon after germination.

Workers clean and bunch beets.

Harvest

Beets are harvested selectively for the largest roots. Roots are three to four inches in diameter when ready to be harvested. The Cylindra variety is more slender, around two inches in diameter, and elongated. Cylindra roots will push themselves up and out of the ground as they mature and become harvest ready. Roots are pulled out of the ground with their greens attached. Piles of beets are made in-row for cleaners and bunchers to follow behind the harvesters. For largest beets, only three to a bunch is sufficient. Bunches with medium to smaller beets will include four to six total beets. Brown, torn, and damaged leaves are removed by hand. Beets are gathered together and secured with a rubber band or twist tie at the lowest part of the leaves, closest to the top of the root. Bunches are stacked upright in harvest totes. Beets can be harvested a day or two in advance of distribution.

After the first harvest, subsequent harvests are made weekly as the other remaining beets mature in size. No more than three harvests are made from a given planting before all beets will be cleared out. In the second and third harvests, all greens are removed using a small, serrated knife. Only a quarter inch of stem should be left attached to the beet root. Greens are left in the field, and roots are loaded into harvest bins.

Chard is also selectively harvested, ideally on the day of distribution. Individual stalks are removed from the plants, starting with those leaves that are the largest. Chard leaves are harvested when the leafy part above the stem is at least six inches in length. Some leaves will be over a foot long. Leaves with many tears, holes, or similar issues are removed from

Examples of five-, four-, and three-beet bunches, based on size.

CROP HANDBOOK: BEET AND SWISS CHARD

Family: *Amaranthaceae*

Beets pulled for bunching, with Cylindra at left and Chioggia at right.

Banding chard leaves on their stems close to the leaf base.

A twist tie holds the bunch together as harvesters continue to pick leaves.

the plants and discarded. In this way, the plants are cleaned during the harvest process. All leaves should be gathered in hand with the lower leaf margins in alignment. This allows for tighter, cleaner bunching. A rubber band or twist tie secures the bunch at the top of the stem, closest to the leaf base. Each bunch should contain six to 10 leaves, depending on size of leaves. After bunching, a lettuce field knife is used to trim the bottom stem ends to make them even. Bunches are packed upside down into harvest totes.

Yield

Beet yield varies by variety. Red beet average yield is 0.85 pounds per row foot, while the specialty types of gold and Chioggia yield around 0.57 pounds per row foot.

Beets are given out as bunches one or two times and then as roots only two or three more times. Members receive one bunch, or one to two pounds of roots, for each distribution.

Swiss chard yields 0.3 to 0.4 bunches per row foot. It is given out in CSA shares five or six times, and it is sometimes a choice item with other bunched greens like kale. Members receive one bunch of chard at each distribution.

Post-harvest Handling

Beet bunches are washed using the bunched washing station. Bunches are packed into light- or dark-green bins, in alternating layers.

Any beet bunches not delivered or sold will have their greens removed. All beet roots are washed using the barrel washer. Beet roots will be packed into light-green bins and weighed.

Chard bunches are washed in the dunk tank with the bubbler. Bunches are checked for leaf quality. Greens are packed and counted into dark-green bins in alternating layers.

Bunched beets are washed on the bunched washing station.

CROP HANDBOOK: BEET AND SWISS CHARD

Family: *Amaranthaceae*

Beet roots are washed in the barrel washer, then sorted and weighed.

Touchstone Gold beets bunched for a CSA share.

Bunched Red Ace beets with greens.

Bunched Bright Lights chard.

Storage

Beets and Swiss chard are stored at 32°F. Plastic pallet covers should be placed over the bins to retain moisture. Swiss chard is good for 10 to 14 days in the cooler. Beet roots without greens will store for three to five months or more.

CROP HANDBOOK: BOK CHOY AND NAPA CABBAGE

Family: *Brassicaceae*

Varieties

For bok choy, smaller types like Mei Qing Choi are preferred.

For napa cabbage, a smaller head like Minuet is grown.

Napa cabbage and bok choy are fast growing, maturing in 45 to 50 days from transplant.

Greenhouse Production

Bok choy and napa cabbage are seeded into 128-cell Winstrip trays. These crops will be in the tray for four weeks prior to planting.

Field Preparations

Napa cabbage and bok choy are transplanted into bare ground in the field system. In the biointensive systems, plants are grown in three rows, and two lines of drip tape are laid on top of the bed at planting.

Bok choy requires 125 pounds of nitrogen per acre, while napa requires 150 pounds of nitrogen per acre. All fertilizer is applied at planting.

Transplanting

Plant spacing varies by production system. Bok choy and napa cabbages are planted at nine inches in the field with the Mechanical Transplanter planter.

Both bok choy and napa cabbage can be grown in biointensive systems at six-inch in-row spacing with three rows per bed. At the six-inch spacing, bok choy and napa cabbage will be hand-planted.

Earliest planting date in central Kentucky is March 25, and latest is July 31. While bok choy and napa cabbage can be grown in tunnels for overwintering, they do not hold very well and will bolt readily in spring.

Mature bok choy, ready to harvest.

Napa cabbage has a defined interior head with a few outer leaves that may be loose.

CROP HANDBOOK: BOK CHOY AND NAPA CABBAGE

Family: *Brassicaceae*

Cultural Practices

Flea beetles are a major pest of both bok choy and napa cabbage. Plants are covered with 47-gram ProtekNet insect netting at the time of transplanting. Hoops are used to keep the net from touching the plant leaves and deter any feeding through the net.

Crops are basket weeded and finger weeded in the field, which requires moving the net and hoops. In biointensive plots, crops are scuffle hoed or hand-weeded as needed.

Harvest

Bok choy and napa cabbage are best harvested using a lettuce field knife or a harvest machete.

For napa cabbage, harvest readiness is checked by lightly pressing down in the top center of the head. There should be resistance where the leaves have developed and curved to form a rounded top. If the top is very loose, it needs more time to fill out the head.

Heads are harvested at the base of the plant, near where the stem meets the soil. The knife is positioned parallel to

Rounded top of a napa cabbage head is firm when pressed with fingertips.

Bok choy are gently nestled upside down into a bin.

Family: *Brassicaceae*

the soil surface and sliced through the stem. Workers take care not to dig the knife into the soil during harvest, as this can create a buildup of dirt on the blade, particularly in wet soil conditions.

For bok choy and napa cabbage, it is critical to cut at the correct height. If the plant is cut too high, the head will fall apart as loose leaves. If the head is cut too low to the ground, it may necessitate a second trimming cut. The cuts should be flush and even. Place bok choy and napa cabbages vertically in bins, with cut ends facing up. Aim for 12 heads or more per bin for maximum bin efficiency. Bok choy leaves can easily crack, so they are handled gently. To place gently in bins, position hands around the leaves as the head is nestled into the bin, keeping leaves pointed in the same direction to prevent bending and breaking.

Yield

Napa cabbage yields 0.8 to 0.95 heads per row foot. Bok choy yields 0.75 to 1.0 heads per row foot.

In CSA shares, bok choy and napa cabbage are specialty crops that are given out only one or two times a year. Bok choy and napa cabbage are fast growing and provide good options for quick greens to diversify leafy greens in CSA shares.

Post-harvest Handling

Bok choy and napa cabbage heads are washed in the dunk tank. A bubbler helps to agitate leaves in case any insects are at the base of leaves. Heads are firmly shaken upside down when removed from the tank. The heads are counted and placed on their sides or upside down into dark-green bins to encourage water drainage.

Bok choy is washed in the dunk tank and packed on their sides in dark-green bins.

CROP HANDBOOK: BOK CHOY AND NAPA CABBAGE

Family: *Brassicaceae*

Both napa cabbage and bok choy can be laid on their sides in bins, or packed upside down.

Storage

Bok choy and napa cabbage are stored at 32°F. Bins are covered with plastic after being set in stacks inside the cooler.

Bok choy is best distributed within a few days but may last up to 14 days in the cooler. Napa cabbage can store in the cooler for two months. Some outer layers of leaves will need to be peeled when yellowing occurs in longer term storage.

CROP HANDBOOK: BRAMBLES, BLACKBERRY, AND RASPBERRY

Family: *Rosaceae*

Varieties

Blackberries grown are Osage, which is an erect variety, and Triple Crown, which is a semi-erect variety.

Raspberries grown are Prelude, which is a thorny, summer-bearing variety with medium to large berries. It will produce both a summer and a smaller fall crop. The second variety grown is Joan J, which is a thornless primocane variety, bearing fruit on the first year's canes in the early fall. Berries are large and firm.

Field Preparations

The bramble patch was spaded and cultivated prior to installation. Compost was applied at 10 tons per acre rate. Soil tests were done to confirm that the pH was between 5.5 and 6.5.

The brambles were established under a Haygrove system. The Haygrove plastic over the bramble plot aids in cane establishment. In the third year, the plastic from the Haygrove system was destroyed in an ice storm. No change in plant vigor and production has been observed since the loss of the plastic.

Brambles require 50 pounds of nitrogen per acre rate at planting and annual applications during dormancy in February or early March. The rate of nitrogen may need to increase beyond 50 pounds per acre, reaching up to as much as 150 pounds per acre in the following years if plant vigor is reduced. Indicators of plant stress include shorter and thinner canes and foliage that begins to yellow.

Transplanting

Berries are purchased as bare-root plants and planted in early May. Raspberries are spaced 24 inches apart in-row, and blackberries are spaced 36 inches apart in-row. Bare-root plants are hand-planted, using a tape measure to keep accurate spacing in-row. Irrigation drip tape lines are laid on top of the soil next to the berry plants. Rows are spaced six to eight feet apart.

Cultural Practices

After planting, strips of woven landscape fabric are installed with sod staples in between the rows of the brambles. Each row of brambles is allocated a row 12 to 18 inches across for canes to emerge. The landscape fabric defines the growing area, helps to control canes from spreading beyond the planted zone, and controls weeds.

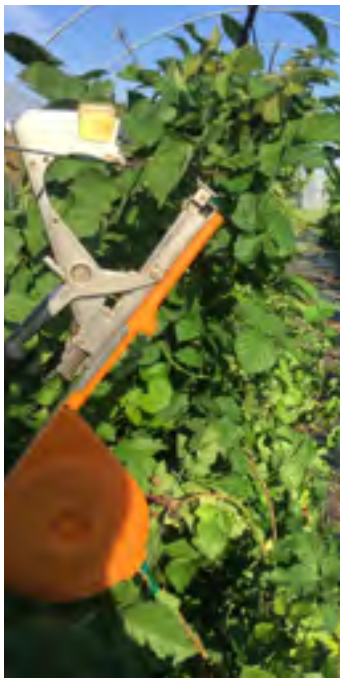
Wood mulch is applied in-row. Mulch can be reapplied annually as needed, to help with weed control.

Brambles require a trellis. Each trellis post is constructed out of a metal T-post, spaced between 15 and 25 feet apart

Bare-root canes are hand-planted with a measuring tape for proper spacing.

Berries are established in a plot with landscape fabric between rows and mulch in-row.

Berry trellis component is made of a metal T-post with two crosspieces and a PVC tee at the top to lift the net above the plants.



A Max Tapener handheld tying machine secures canes to the wires as they grow.

CROP HANDBOOK: BRAMBLES, BLACKBERRY, AND RASPBERRY

Family: *Rosaceae*

Old floricanes are pruned to the ground and removed.

in row. The T-posts are fitted with metal crosspieces at three feet and five feet high. The lower crosspieces are 18 inches long, while the upper crosspieces are 24 inches long. Crosspieces are held tight to the T-posts with U-bolts and nuts. An 11-gauge wire runs through the crosspieces, secured in notches on top of the crosspieces. The wires create a lower and an upper channel for the canes to grow up into, forming the shape of a V. The wires are angled down at each plot end and secured to an anchoring T-post installed into the ground at a 45-degree angle, away from the plot. Each anchoring T-post is connected by 11-gauge wire to a helical soil anchor for stability. Each wire is wound on a ratchet-style wire tensioner. Over time, the wire may need minor adjustments to keep it tense as it holds more weight from the canes. As the canes begin to grow, they are tucked inside the trellis wire and secured to the wire when they are small, using a Max Tapener handheld tying machine.

Brambles require pruning in late winter or early spring. If the canes are beginning to push out new leaves, the canes should be pruned soon. Mid-March is a general target time for pruning. Both raspberry varieties are pruned at the same time, which gives two crops for Joan J instead of just one in the fall. The raspberry floricanes are cut down to the ground and removed. The remaining canes are thinned to four canes per row foot, or eight per plant. The canes are also cut back to about four feet in height. When thinning, remove the skinniest canes.

Blackberries are pruned similarly. All woody floricanes are removed. Remaining canes are thinned if needed, re-

All canes are topped to four-foot height.

Blackberry laterals, shown here, are trimmed to 18 inches.

Family: *Rosaceae*

The bramble patch prior to pruning.

The bramble patch after pruning.

moving the smallest canes or those spreading to the edges of their planting zone. At least three to six healthy canes are left per plant foot. All canes will be cut back to four to five feet. Blackberries also have many side shoots, called laterals. Laterals are trimmed to 12 to 18 inches. Any damaged canes are removed entirely.

Netting with 70-gram ProtekNet netting, rated for the spotted wing drosophila (SWD), is essential for high-quality berries. Once the berries are beginning to color, the net is pulled over the plants. PVC pipes are trimmed and attached to PVC tees on top of the T-posts holding the trellis. The netting is laid atop the PVC tees. Two large nets are sewn together to create a single net to fit the berry plot, which is 100 feet long by 25 feet wide. Enough netting is given to reach all the way to the ground on all four sides. On the long sides, the net is held down with pavers spaced every five to 10 feet. On the end with the trellis anchors, sections of pool noodles are fitted over the wire tensioners to prevent snagging and tearing of the net. The net is tied shut on the anchor ends with thread or fishing line and clipped with large binder clips to keep it closed and secured.

The plot is monitored to ensure no animals, like birds, get under the net and become trapped. If any bird becomes trapped under the net, one of the sides is opened so the animal can be released safely.

While netting may exclude pollinators, pollination has never been an issue, even with the netting in place.

Once the harvest season is complete, the netting is removed and stowed over winter until the following season.

Two large pieces of ProtekNet netting are sewed together using a handheld sewing machine. Photo courtesy of Gonthier Lab.

ProtekNet netting is weighted to the ground with pavers.

Netting covers the entire berry plot overhead and on all sides for protection from spotted wing drosophila and harvest ease.

CROP HANDBOOK: BRAMBLES, BLACKBERRY, AND RASPBERRY

Family: *Rosaceae*

Harvest

Berries are harvested by hand into pint- or quart-sized Berigard molded-fiber berry boxes. Ripe berries will come off the plant when tugged lightly. If they do not come off readily, they are not ripe. Berries are part of the UK-CSA you-pick and are not harvested for inclusion in weekly CSA shares. Daily or every-other-day harvest is best when berries are in season. Frequent picking by CSA members keeps the plants productive, and few berries are lost to overripening.

CSA members are instructed on harvesting technique and reminded to ensure the netting stays weighted down after harvest. Wearing gloves may be desired when harvesting from thorny varieties like Prelude. For marketable fruit, it is critical to ensure minimal damage during the harvest and post-harvest stages to maintain the fruit's firmness. Pick berries directly into the final container that will be given out or sold to minimize handling or number of touches on the delicate berries.

Yield

Overall yield is not tracked, since the brambles have been in production as part of a you-pick operation.

Post-harvest Handling

Berries are not washed on-farm.

Storage

Berries are best stored at 32°F and should be consumed within three to five days.

Ripe blackberry.

Ripening raspberries.

A CSA member you-picks ripe raspberries.

CROP HANDBOOK: BROCCOLI AND CAULIFLOWER

Family: *Brassicaceae*

Varieties

Broccoli varieties grown in spring are Belstar, Gypsy, Green Magic, and Lieutenant. Imperial is grown in early summer and fall. Other fall broccoli varieties grown include Emerald Crown and Belstar. Arcadia and Marathon do well in the latest planting windows.

Earliest broccoli matures in 56 days from transplant, while later varieties take up to 68 days.

Cauliflower varieties grown include Bishop, Denali, Flamestar, and Steady. The only romanesco variety grown is Veronica.

Cauliflower matures in 50 to 78 days from transplant.

Greenhouse Production

All broccoli and cauliflower are seeded into 128-cell Winstrip trays. Most will be in the tray for four weeks. Any greenhouse broccoli and cauliflower started in midsummer will do best under misters for better germination.

Field Preparations

Both broccoli and cauliflower are grown in the bare-ground production system. On occasion, in order to get an early start, they are transplanted into plastic mulch. However, they risk overheating prior to maturity.

Transplanting

Broccoli is planted with 12-inch in-row spacing. Cauliflower requires 18-inch in-row spacing.

Earliest recommended planting date for central Kentucky is April 5, and latest is August 1.

Broccoli requires 100 pounds of nitrogen per acre, while cauliflower is a heavier feeder, needing 150 pounds of nitrogen per acre. Broccoli will get all fertilizer applied at time of transplanting, but cauliflower receives two-thirds of the nitrogen requirement at planting and one-third from fertigation after eight weeks of growth.

Cultural Practices

The most common insect pest pressures for broccoli and cauliflower are aphids during warm spells, imported cabbage worm, cutworm, flea beetle, and harlequin bug. Plants transplanted in the summer for fall production are covered with 47- to 60-gram ProtekNet netting to protect from the harlequin and the flea beetle. Timely sprays of Bacillus thuringiensis (Bt) will keep worms in check.

White cauliflower will turn yellow from sun exposure unless it is blanched. To blanche the heads, two or three of the leaves surrounding the interior head are broken at the mid-

Broccoli plants are grown in a large quantity to meet CSA expectations.

Example of a cauliflower with partial self-wrapping.

CROP HANDBOOK: BROCCOLI AND CAULIFLOWER

Family: *Brassicaceae*

This white cauliflower will be best covered by breaking adjacent leaves over top to protect it from yellowing.

rib and flopped over top of the head. This can be done by workers walking the field and snapping leaves for one row at a time. This only needs to be done when plants are not good at self-wrapping the heads and the white heads are beginning to be revealed at the plants' centers. Since this discoloration is a larger issue in the spring, non-white varieties are grown to avoid the need for blanching, with white cauliflower being grown primarily in fall.

Harvest

All broccoli and cauliflowers are best harvested using a lettuce field knife or a harvest machete.

Cauliflower is harvested below the curds, and the closest wrapper leaves are kept attached. Harvest starts when the heads are between five and six inches across. Some varieties will go up to 10 inches and may weigh as much as four pounds each. Romanesco is a specialty type of cauliflower that forms cylindrical heads with fractals like miniature seashells, exhibiting a Fibonacci sequence. This cauliflower does best in fall and is harvested at a slightly smaller base diameter, starting around four inches. It is difficult to see where the base of the head lies, as many of the lower leaves curl underneath the head. Some smaller leaves are retained, but workers cut heads lower initially and then trim them, until they become familiar with this crop's growth pattern.

Broccoli are not harmed by dew and can be harvested wet.

When florets loosen, harvest if the head is at least the size of a fist.

Romanesco cauliflower is a stunning fall favorite.

CROP HANDBOOK: BROCCOLI AND CAULIFLOWER

Family: *Brassicaceae*

Broccoli, when harvested as a crown, is cut close to the florets. However, most broccoli is harvested with a longer stem attached. The harvest knife is placed four inches below the crown and cut cleanly through. Several leaves may still be attached. The largest, lowest leaves are removed by hand, and two or three smaller leaves are left attached. Broccoli needs to be harvested a minimum of twice a week when in season. The florets must be tight, compact, and have full color. Once florets become enlarged and loosen, the head is past its prime. In addition, heat stress can cause uneven development, with some florets being taller than others, giving an uneven appearance to a usually smoothly rounded head. This will not improve over time, and the head should be harvested without delay. Heads that are beginning to loosen are ideally at least the size of a fist. If smaller heads must be taken due to heat stress, the smaller heads are bundled together for an amount equivalent to a normal head.

Broccoli occasionally exhibits a hole in the middle of its stem. This hole can indicate a boron deficiency, boron uptake deficiency, or a nitrogen surplus. If a soil test indicates boron is less than one pound per acre for the field, additional boron may be needed. Otherwise, the hole may be from nitrogen. The hole in the stem does not usually cause rot, but fruits are inspected at harvest and discarded if any secondary rot occurs.

Some purpling discoloration may occur on broccoli heads during cold weather due to inhibition of phosphorus uptake, but the head is not harmed.

Broccoli harvest can be done quickly with a conveyor, with a worker walking each aisle and checking two rows of plants on either side to harvest. Broccoli can also be harvested in pairs, with one person cutting while the second follows behind, carrying the bin until full.

Yield

Cauliflower average yield is 0.3 to 0.6 heads per row foot. Broccoli yields 0.65 to 0.8 heads per row foot. Romanesco yields on average 0.3 to 0.45 heads per row foot.

In CSA shares, broccoli is a staple crop and is given out for two to four weeks in early summer and two to four weeks in fall. Cauliflower is a specialty crop that is given out only one or two times a year. Cauliflower is one of the more challenging brassicas to grow, in large part because they are in the ground for so long and it is risky to try to plant them early enough to have them ready before the CSA season ends. They are much more reliable for later fall and are great crops for Thanksgiving, particularly romanesco types.

A hole in the stem may indicate a boron deficiency.

Broccoli is harvested efficiently with a conveyor.

On the harvest wagon, broccoli is packed into bins for transport to the packing shed for washing.

CROP HANDBOOK: BROCCOLI AND CAULIFLOWER

Family: *Brassicaceae*

Post-harvest Handling

Cauliflower and romanesco are not washed. They are counted and packed into light-green bins with only two layers.

Broccoli is washed in a dunk tank. A bubbler will help to dislodge any insects hiding underneath the florets or in the branching stems. In warmer months, broccoli will benefit from an ice bath for better cooling. Broccoli can also be top-iced, but a plastic barrier under the ice may be desired; ice can also be added to the bottom of the bin instead. Direct contact between melting ice and broccoli florets can cause water-soaking of the tissues. Broccoli is counted and loaded into light- or dark-green bins.

Storage

Broccoli and cauliflower are stored at 32°F. Bins are covered with plastic to trap moisture.

Broccoli has a storage life of about seven to 10 days, while cauliflower may hold in storage for up to three weeks.

Broccoli harvested when warm is dunked in an ice bath.

Broccoli is harvested with four-inch stems for CSA shares.

Cauliflower and romanesco can be harvested with a few of their closest wrapper leaves still intact.

CROP HANDBOOK: BRUSSELS SPROUTS

Family: *Brassicaceae*

Varieties

Brussels sprouts used for earlier harvest include Jade Cross and Franklin. Later-maturing varieties grown include Divino and Diablo. Jade Cross does not respond well to pinching.

Early-maturing varieties are ready in 85 days, and longer varieties may take 100 to 120 days, both from transplant.

Greenhouse Production

All brussels sprouts are seeded into 128-cell Winstrip trays. They are grown for four weeks before transplanting.

Field Preparations

Brussels sprouts are transplanted into bare-ground fields.

Transplanting

Brussels sprouts are spaced in-row at 23 inches, with two rows per bed.

Brussels sprouts need 150 pounds of nitrogen per acre, which is partially applied at time of planting. Since they are a long-season crop, a third of their nitrogen requirement is supplied by fertigation after eight to 10 weeks of growth.

Cultural Practices

Brussels sprouts are susceptible to many of the same pests year after year. The most common are aphids during warm spells, imported cabbage worm, cutworm, flea beetle, and harlequin bug. The harlequin bug is the primary pest of brussels sprouts and may attack the earliest fall plantings the most. Brussels sprouts are covered with 60-gram ProtekNet netting immediately after planting. Later plantings of brussels sprouts will also benefit from netting. Harlequin bugs feeding on leaves can weaken the plant defenses and may exacerbate disease issues. Hoops are placed over plants to keep the net from

Harlequin bugs cause significant damage. Feeding pressure coupled with heavy rains were optimal conditions for Alternaria.

Netting protects crops, but white chlorosis on leaf is evidence of harlequin bugs feeding through the net.

Family: *Brassicaceae*

touching the surface, as harlequins may still feed through the netting when it is in contact with the leaf surfaces. As plants grow, they will eventually touch the net when regular wire hoops are used, but by then damage is minimized.

During wet periods, *Alternaria* can become a significant disease issue. Chemical sprays of Bt control the cabbage worms, and insecticidal soap controls the aphids.

Nets are removed periodically to allow for two cultivations with the finger weeder, and then the nets are replaced.

Harvest

Brussels sprouts are harvested in two different ways. Sprouts can be left on the stalk with a single, whole-stalk harvest, or the sprouts can be pulled off the stalks individually. If desiring a full stalk, it is important to encourage even development of all the sprouts by removing the apical meristem, which is the growth point at the top of the plant. Simply twist the tip of the stem off the plant by hand at a minimum of four weeks prior to intended single-cut harvest. Most sprouts benefit from five to six weeks after pinching for full-stalk development.

When it is time to harvest, leaves are stripped off the stalks of any that are ready to take. Either a leaf-stripping crew is sent down the rows first, with a cutting crew following behind, or stripping and cutting is done at the same time by one person. Stripping helps to identify which plants are ready and streamlines the cutting stage. To strip, simply grab leaves and pull down. Plants can also be "karate-chopped," with arms moving down the plant on either side to break all the leaves.

Pinching off the top of a brussels sprout plant for full-stalk harvest.

Stalks are roughly stripped of leaves in preparation for cutting.

Harvesters follow cleaners and position tobacco machete below the last sprout to cut.

CROP HANDBOOK: BRUSSELS SPROUTS

Family: *Brassicaceae*

Stalks are kept vertically in bins, or they are piled into a macro bin until being counted in the pack shed.

When ready to cut, harvest machetes or tobacco knives are used to slice the thick stems off at the base. The stalks are very thick and may require two or three cuts to separate them from the roots. It is important to make sure knives have been sharpened prior to harvest. Cut stalks are stacked upright in harvest totes. Full totes are moved to the packing shed, or they can be emptied into a clean macro bin for counting and storing.

To harvest individual sprouts, do not remove the growth point. Sprout harvest is a preferred method when desiring to get multiple harvests off the crop, or when desiring to overwinter the plants. Start with the mature, rounded sprouts at the bottom and work your way up. Simply pull down on each sprout with a slight twist to separate and collect individual sprouts in a harvest bin. Be sure that the sprouts cannot fall through any holes or slits in the bins.

Yield

Brussels sprouts yield 0.15 pounds per row foot for early harvest, or 0.5 stalks per row foot for late harvests.

In CSA shares, brussels sprouts are a specialty crop that are given out only one to two times a year. Brussels sprouts are the most challenging brassica to grow, in large part because they are in the ground for so long, and it is risky to try to plant them early enough to have them ready before the CSA season ends. They are much more reliable for later fall and are great crops for Thanksgiving.

Snapping off individual sprouts is a different harvest technique.

CROP HANDBOOK: BRUSSELS SPROUTS

Family: *Brassicaceae*

Post-harvest Handling

Brussels sprouts are not washed unless necessary.

Brussels sprout stalks are hard to pack and stack. If stalks are short or can be split in half, they can be counted and stored in dark-green bins. Taller stalks can be held upright in harvest bins or dark-green bins, but they will not be stackable. Large amounts of stalks can be stored easily in a macro bin. Individual sprouts can be held in yellow bins or weighed into quart containers that are lined up in yellow bins.

Stalks are tabulated by count, while loose brussels sprouts are tabulated by weight.

Storage

Brussels sprouts are stored at 32°F.

Bins should be covered with plastic to trap moisture. However, a large macro bin of brussels sprout stalks will give off significant field heat and should not be covered until end of day or the following morning after harvest.

Brussels sprouts will hold in the cooler for two weeks or more.

Loose sprouts are kept in yellow bins. They are weighed into quart-sized berry containers.

CROP HANDBOOK: HEAD CABBAGE

Family: *Brassicaceae*

Varieties

Various head-cabbage varieties are grown, including Farao, Bronco, and Storage No. 4 (green heads); Omero, Red Express, and Ruby Ball (red heads); Famosa (savoy); and Caraflex (conical).

Early head cabbages like Farao and Caraflex mature in 65 days, while main-season or storage-cabbage varieties like Bronco, Storage No. 4, and Famosa mature in 85 to 95 days, all from time of transplanting.

Clockwise from top left: Storage No. 4, Red Express, Caraflex, and Famosa

CROP HANDBOOK: HEAD CABBAGE

Family: *Brassicaceae*

Greenhouse Production

All cabbages are seeded into 128-cell Winstrip trays. They are ready after four weeks of growth.

Field Preparations

Cabbages are transplanted into bare ground.

Transplanting

Head cabbages are spaced 16 inches apart in-row.

Head cabbages require a total of 150 pounds of nitrogen per acre. Two-thirds of the fertilizer requirement is applied at planting, while the final third will be fertigated after eight to 10 weeks of growth.

Earliest planting date in central Kentucky is March 25 and latest is July 31 for cold-tolerant savoy types.

Cultural Practices

Head cabbages are susceptible to *Alternaria* and insect pests like aphids, imported cabbageworm, cabbage looper, and harlequin bugs. When possible, head cabbages are covered with 60-gram ProtekNet netting at time of planting. Plants are cultivated with the basket weeder and finger weeder until heading begins.

Harvest

Cabbages are best harvested using a lettuce field knife or a harvest machete.

Cuts are made at base of head but above the loose, wrapper leaves. If the heads are intended for long storage, keep several wrapper leaves intact. If heads will be handed out immediately, only a single wrapper is sufficient. Push back extra wrapper leaves to make the head more visible and easier to cut.

Inspect heads for worm and bug damage; frass can be seen at the base of the wrapper leaves. Tunneling may indicate a pest has burrowed inside, in which case successive layers can be torn off to remove any yellowed area. A pest hidden below the top layer may be too far down to make the peeling worthwhile. If a few layers are peeled off the cabbages, a second cleaning cut on the stem may be needed to keep it flush with the head. The stem should not extend past the last layer of leaves more than one-eighth inch.

Head cabbages during an extremely wet season experienced harlequin bug pressure and then succumbed to Alternaria. The entire crop was a loss.

Worker pushes back outer leaves to get clearer view to cut.

CROP HANDBOOK: HEAD CABBAGE

Family: *Brassicaceae*

Cabbages are tossed from harvester to intermediary to wagon.

Large cabbages are best harvested using a conveyor and loaded into macro bins, or they can be tossed after all the cuts have been made. Tossing cabbages requires three to five people: one worker to drive the tractor, one or two to catch cabbages on the wagon, and one or two to throw cabbages from the field to the person on the wagon. The person on the wagon is responsible for placing them in a macro bin after they are caught. If cabbages are dropped, they are set aside for a cull bin; the force of impact will frequently cause the head to split, even if it is not immediately visible.

Yield

All head cabbages have an average yield of 0.45 to 0.60 heads per row foot.

In CSA shares, head cabbages are given out four to six times a year.

Post-harvest Handling

Head cabbage can be washed on the brush washer or washed directly on the conveyor. For maximum efficiency, the conveyor on the harvest wagon can be angled off the wagon into an open pack shed doorway with a macro bin sitting near the end. Cabbages are unloaded in reverse, from a macro on the wagon onto the belt, moving the cabbages into the packing shed. Using a hose midway up on the conveyor, cabbage heads are sprayed quickly, particularly the cut end, which is usually where dirt may be adhered. After the quick spray,

Savoy cabbages are loaded onto the conveyor at harvest.

CROP HANDBOOK: HEAD CABBAGE

Family: *Brassicaceae*

The conveyor is angled into the pack shed and reversed to send cabbages down the line for a spray wash. Cabbages are then counted and loaded into a clean macro bin.

Leaving more wrapper leaves on cabbage heads prolongs storage in macro bins.

heads are picked from the end of the conveyor and placed gently into a second clean macro bin. Heads are counted as they are loaded. Smaller head cabbage amounts are counted into dark-green bins.

Cabbages are counted as they are packed in a macro bin, and the final count is recorded with a label on the bin. When counting smaller heads into dark-green bins, only five to 10 cabbages fit inside each bin. Label each bin with the number of cabbage heads per bin when the count is not consistent for every bin.

Storage

Head cabbage is stored at 32°F.

A large macro bin of cabbage will give off significant field heat and should not be covered until end of day or the following morning after harvest. Other bins can be covered with plastic after being set in stacks inside the cooler.

Cabbage can be stored in the cooler for two months. Some outer layers of leaves will need to be peeled when yellowing occurs in longer-term storage.

Storage No. 4 cabbage can hold for six months or longer in proper storage. Keep as many wrapper leaves on the heads as possible. Remove the outer leaves when ready to distribute. A second washing or quick spray may be needed after pulling them out of long-term storage. The cut ends may also need to be trimmed and rinsed.

CROP HANDBOOK: CANTALOUPE

Family: *Cucurbitaceae*

Varieties

Athena cantaloupe is preferred for its size, shelf life, and disease tolerance. Fruits are five to six pounds each. Smaller, Tuscan types like Wrangler also produce well.

Cantaloupe matures in around 79 days from transplant.

Greenhouse Production

Cantaloupe is hand-seeded into 72-cell Winstrip trays. Plants require only three weeks in the greenhouse, as they are more vigorous than watermelons.

Athena cantaloupe ready to harvest.

Field Preparations

Cantaloupe is grown on white plastic mulch beds when netted, or aluminized plastic mulch if unnetted. No living mulch is planted. Plastic beds are cultivated several times prior to planting. Each field holds six or seven beds for melons, spaced at least seven feet or eight feet apart respectively.

Cantaloupe requires 120 pounds of nitrogen per acre. Two-thirds of the required fertilizer is applied pre-planting, at time of plastic laying. Cantaloupe is then fertigated with the remaining nitrogen requirement after eight to 10 weeks.

Transplanting

Cantaloupe is transplanted using the water wheel setter, in a single row per bed at 30-inch in-row spacing. They can also be grown at closer spacing, but 30 inches allows for more uniform vining out.

Earliest planting date is May 10, and latest is July 1.

Cultural Practices

Beds are netted with 60-gram ProtekNet netting at time of planting. Plastic beds are cultivated one or two times after planting. The nets are removed and replaced at each cultivation. The final cultivation may require manually moving any vines that have fallen off the bed top back onto the bed. After this final cultivation, the plant is left to grow into the rows and shade out weeds. Nets are removed for pollination for two weeks, once both male and female flowers are present.

Cantaloupe is netted for protection from insects.

CROP HANDBOOK: CANTALOUPE

Family: *Cucurbitaceae*

Green lacewing eggs are released three times after planting, with releases spaced a week apart, to control aphid outbreaks. Plants are misted prior to scattering eggs at dusk.

These vines are coming off the bed and will be pushed back on top for one final cultivation between rows.

Cantaloupe is routinely afflicted by aphids when young. Every growing season, three weekly releases of green lacewing eggs are made, starting right after transplanting. Eggs are spread out across all the cantaloupe beds, and plants are misted prior to shaking the eggs around the plant bases.

Many diseases attack cantaloupes, depending on the growing season's climatic conditions. Common issues include powdery mildew, downy mildew, gummy stem blight, and anthracnose. Protectants, which may include *Bacillus subtilis*, *Bacillus pumilus,* neem, and copper, are applied on a 10-day cycle starting in the early growth phase.

Irrigation is withheld in the last two to four weeks of maturation to increase melon sweetness.

Signs of gummy stem blight on leaves, top, and fruit stem, bottom.

CROP HANDBOOK: CANTALOUPE

Family: *Cucurbitaceae*

Harvest

Cantaloupes are checked daily leading up to harvest. A daily harvest is not possible, therefore they are harvested twice a week, on either Mondays and Wednesdays or Tuesdays and Thursdays, depending on readiness. Cantaloupe is harvested in the field using the conveyor. The conveyor wagon is preset with two macro bins situated on either side of the conveyor prior to being taken to the field. Workers walk in between each bed and check both beds on left and right, as well as the area in between, for melons ready to harvest. Harvest is selective for ripe cantaloupes.

Prior to harvest, one or two cantaloupes are cut open to determine readiness and taste for sweetness. Harvest indicators include size of melon; full development of netting around the melon; color change from green to yellow under the netting; and three-quarters or full slip of the stem. Full slip is when the stem is tugged gently and detaches completely from the fruit, leaving a slightly hollow stem scar. When the stem cannot be removed easily or is broken, leaving some stem tissue attached, the melon is not at full slip. Once harvest begins, workers pay attention to which melons give full slip to determine the ideal melon.

Stem being pulled by hand off of melon.

This cantaloupe was at three-quarters slip, as a small stem residue was left behind on the right side.

This cantaloupe is at full slip.

CROP HANDBOOK: CANTALOUPE

Family: *Cucurbitaceae*

Cantaloupes are harvested by hand and placed on the harvest wagon conveyor belt. Melons are stacked gently into macro bins on the wagon.

Melons are removed from plants by hand, with the stem being gently pulled away from the top of the fruit. Melons are placed individually onto the conveyor. The conveyor will carry the melons to the harvest wagon, and workers place melons into a macro bin. Melons should not be dropped into the bins as they can crack. When field conditions do not require melons to be washed, they are counted at time of harvest by the worker placing them into the macro bins.

Yield

Cantaloupes yield 0.40 fruits per row foot.

Cantaloupes are given out in CSA shares two or three times a year. Each share receives one to two melons per distribution.

Post-harvest Handling

Cantaloupes are not washed unless absolutely necessary due to muddy field conditions. When muddy, they are washed in the brush washer. If washing is not necessary, cantaloupes can be kept in a clean macro bin and moved from the harvest wagon to the packing shed using a forklift, where they are maneuvered into the cooler for room cooling.

Storage

Cantaloupe is optimally stored at 34°F to 38°F. After field heat is removed, plastic pallet covers go over the tops of the macro bins.

Cantaloupe does not store long and is best distributed within two to three days of harvest.

Cantaloupe macro bins are moved using a forklift.

CROP HANDBOOK: CARROTS

Family: *Apiaceae*

Varieties

Spring varieties include Mokum and Yaya . Main-season preferred variety is Romance. Late-season and storage varieties include Bolero, Hercules, and Yaya.

Spring carrots mature in 54 days, main season in around 70 days, and late season in 75 days or more after direct seed.

Field Preparations

Carrots are grown in the bare-ground production system. The stale seedbed cultivator goes over beds three to four times over the course of three weeks prior to planting. Alternatively, instead of the cultivator, the Pyroweeder flame weeder is used weekly over three weeks. The flame-weed method results in less soil disturbance; however, flaming will not kill grasses.

Direct Seeding

Carrots are direct seeded with the MaterMacc VegiMacc. NOP-compliant pelleting on seed is preferred for proper seeding rate. Soil should be friable and loose; carrots seeded on rocky soil or soil with high residue can become stunted or branched.

Carrots are spaced apart 0.8 inches in row, at a depth of 0.25 to 0.5 inches. MaterMacc seed plate 144, 2.5 is used for pelleted seed and sprockets are set to 22-17 for 0.8-inch spacing. For unpelleted carrot seed, MaterMacc seed plate 180, 0.8 is used and sprockets are set to 17-18 for 0.8-inch spacing. A Jang push seeder is used when planting intensively, as in high tunnels. The Jang seed roller used for pelleted carrot seed is LJ-12, at two-inch spacing. Carrots are seeded intensively with three or four rows per bed.

Nutrients can often be provided in large part from the previous cover crops. Carrots require 90 pounds of nitrogen per acre, and fertilizer required is banded at time of seeding. Excessive nitrogen can cause carrot malformations like branching and forking.

If seeding carrots for spring, the earliest seeding date recommended is March 20. The latest recommended seeding date for a fall crop is July 15. If overwintering carrots in a tunnel, ideal planting time is early to mid-September. Ideal soil temperature is 77°F for good germination.

Carrots peeking above soil surface.

Carrots are hand-weeded in-row when plants are small.

CROP HANDBOOK: CARROTS

Family: *Apiaceae*

Cultural Practices

Flame weeding is effective for broadleaf weeds in carrot beds. Carrots are flame weeded weekly prior to emergence. Carrots generally emerge in seven to 21 days. Planting a few beets at the end of the row will be an indicator of when carrots will germinate; once beets emerge, carrots are flamed immediately for the last time as they will emerge only a day or two later.

Seedling germination will be aided by even moisture on the bed top, which also prevents soil crusting. If weather does not have rain in the forecast, sprinklers or drip tape laid on the bed tops is used to hasten germination. The most critical irrigation time is for seedling emergence.

After seedlings emerge, the carrots are basket weeded weekly. Once carrots are taller and more established, a finger weeder may also be used. Some hand-weeding in-row may be required, and wheel hoeing the shoulders and wheel tracks may be needed if soil conditions do not allow for use of tractor implements for cultivation.

Carrots are monitored for pests like cutworms, aphids, flea beetles, armyworms, and whiteflies. Carrot diseases are not a prominent issue, and most issues are mitigated by crop rotation and the allowance of prior crop residues to fully break down. Carrots are a minimally to zero-sprayed crop at UK-CSA.

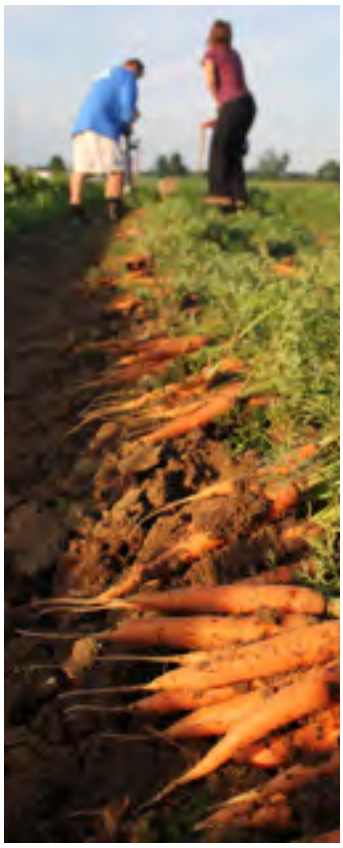
Overwintered carrots are row covered when temperatures go below 20°F. Frosts are tolerated, but hard freezes can kill carrots. Some carrots may survive at temperatures as low as 12°F.

Harvest

Carrot size at time of harvest varies by variety. Mokum is generally a smaller carrot of 5.5 to 6.5 inches in length. Romance is seven to nine inches long, and Bolero is seven to eight inches long. Storage carrots can be held in the ground longer as temperatures decrease. Carrots are harvested either by hand with a digging fork or by using a plastic lifter or undercutter implement. If using an undercutter, be sure the implement can get entirely underneath the carrot root without chopping off the tips.

When digging by fork, the fork is placed two to three inches off to the side of the carrot top. The fork is sunk vertically down into the ground as far as it will go. The fork is rocked back and forth a few times to loosen soil profile. Care should be taken in not bending the fork all the way back, as this risks spearing the sides of the carrots. Once the soil is loosened, the

Digging carrots by fork.



Fork is sunk three to four inches from base of carrot, then carrots are hand-pulled and laid on top of soil.

Family: *Apiaceae*

fork is pulled out and moved down the row six inches to the next section. Carrots can then be pulled out of the ground by grabbing them close to the base of the green tops where they meet the root. Carrots are piled for bunching or clipping off the greens.

For bunched carrots, six to 12 carrots go in a bunch. Any yellowed or brown leaves are removed by hand. Carrots are bunched using a twist tie to hold greens together tightly. For storage carrots without greens, pruners or a serrated knife are used to cut greens a quarter inch from the root top. Any excess greens will degrade the carrot in storage. Clipped carrots are placed in harvest bins for transport to the packing shed.

Carrots should not be dug and left exposed to the sun on top of the soil for long. Only sections that can safely be clipped or bunched within the hour are dug and pulled at one time.

Yield

Yield average is 0.4 bunches per row foot or 0.4 to 0.75 pounds per row foot. Main-crop and fall-crop carrots have higher yield per row foot, as carrots are larger and soil is warmer at time of seeding.

Desired CSA amount is one bunch weighing around one pound each, or one to two pounds of loose roots, per distribution. Carrots are a CSA staple crop at UK-CSA. Carrots show up in early summer (two times), late summer (two times), and fall shares (two to three times). CSA members receive approximately 10 to 15 pounds of carrots a season, between mid-June and mid-October.

Post-harvest Handling

Bunched carrots are best washed at the bunched washing station. Loose roots are washed in the barrel washer, and benefit from an extra spray by the hose when getting started if especially coated in dirt. Loose roots are also washed easily in the dunk tank with the bubbler. Bins that are one-half to three-quarters full are placed on top of the bubbler inside of tank. The water level must be above the carrots in the bins once submerged. With bubbler turned on, carrots are left for 10 to 30 minutes. In the dunk tank, six harvest totes can fit inside at one time. Each tote holds about 40 pounds of carrots. After bubbling, a quick final rinse in the barrel washer may be desired, or they can be transferred immediately to a clean light-green bin for storage. Washed carrot roots are weighed prior to storage.

To view video of the washing process, click on the following link:

Video: Bubbler washing carrots

Bunched carrots washed at bunched washing station.

Loose carrots in barrel washer benefit from extra hose spray.

Barrel-washed carrot roots.

CROP HANDBOOK: CARROTS

Family: *Apiaceae*

Six bins of carrots fit in dunk tank for bubbling.

Carrots washed with dunk tank bubbler.

Storage

Carrots are stored inside the cooler at 32°F to 41°F. Once the field heat has been removed, the bins are covered with plastic pallet covers on top and down the sides for maximum moisture retention. Carrots without greens can be held in storage for six to nine months. Freeze damage will occur if storage temperatures dip below 30°F.

Bunched carrot example for CSA shares.

Loose carrots are bagged in plastic for CSA shares.

CROP HANDBOOK: CELERY

Family: *Apiaceae*

Varieties

Celery varieties used with success include Tango and Merengo. Celery can take up to 100 days to reach maturity after transplanting.

Greenhouse Production

Celery needs 12 weeks in the greenhouse and benefits from potting up during its greenhouse growth. Celery is started in 128-cell Winstrip trays and is potted up to 72-cell Winstrip trays after six to eight weeks.

Transplanting

Celery is best grown under cover in high tunnels. To keep it from getting overheated, it is grown on white plastic mulch. In biointensive management systems, celery is grown with three rows to a bed and nine-inch in-row spacing. For plasticulture systems, celery is still grown with nine-inch in-row spacing, but with only two rows per plastic bed.

For overwintering in high tunnels, a succession of celery can be started in the greenhouse.

Earliest planting date is mid-May, while an overwintering planting in a high tunnel can be transplanted as late as mid-November. Summer celery is transplanted in the beginning of June for a late-September harvest.

Cultural Practices

Proper irrigation management is critical for celery. However, if plants are exposed to too much rain, crown rot can result. Growing them under cover is the preferred growing method.

A frequent insect pest of celery is spider mites. Watch for yellowing and stippling on leafy tops, after which they can be controlled with an insecticidal soap application.

A healthy celery plug shown in a 72-cell Winstrip tray.

Celery succumbed to crown rot during a wet year when not protected under cover.

CROP HANDBOOK: CELERY

Family: *Apiaceae*

Harvest

Celery can be harvested in two different ways: whole head or individual stalks. Production of whole heads for celery is inconsistent, and celery is only harvested as an entire head as a last harvest at the end of the year. Celery is usually harvested by individual stalks. The very first, outermost stalks are usually leafy and short. Just inside these first outer leaves will be the first good stalks to harvest. The length of each stalk should be a minimum of six inches from base to node, where the leaves begin to split off from the stalk. Ideal stalk length is eight to nine inches. Some stalks can be pulled from the base with a firm tug. Otherwise, use a small knife to make a cut as close to the base as possible. A bunch is made from eight to 12 stalks, and a rubber band, placed midway up the stalk, holds them together. Care should be taken to not wrap the band too tightly, as this can compress and break the stalks. End of the stalks are trimmed for a smooth, clean cut.

When removing stalks, the cut end is inspected. Browning in the veins occurs when the stalks are older and turning woody. Any stalks with discoloration visible at the base veins are culled. In addition, cold damage can cause the outer skin of the celery stalks to peel off. These stalks are not marketable and are trimmed from the plant.

After harvest, workers continue to remove yellowed, dead, and diseased-looking leaves and plants from the area to allow for successive harvests.

Start cutting celery stalks from the outer base.

CROP HANDBOOK: CELERY

Family: *Apiaceae*

Individual celery stalks banded at harvest.

Yield

Celery has yielded 1.0 to 1.25 bunches per row foot of plants.

Celery is a specialty herb and is only given out one or two times in CSA shares per year. However, as celery does very well in fall and winter, it is also included in fall shares and at spring farm-stand sales.

Post-harvest Handling

Celery is washed as a bunch with the rinse conveyor or hand sprayed on the bunched washing station.

After washing, bunches are counted and stacked in alternating directions in light-green, dark-green, yellow, or other bins. Celery is lightweight and can be stored in numerous bin sizes.

The last harvest of the season can be a whole-head harvest.

CROP HANDBOOK: CELERY

Family: *Apiaceae*

Storage

Celery is kept in the cooler at 32°F, and plastic pallet covers are placed over the bins for maximum moisture retention.

Banded celery stalks can be washed at the bunched washing station.

CROP HANDBOOK: COLLARDS AND KALE

Family: *Brassicaceae*

Varieties

Collards variety grown is Champion.

Three primary varieties of kale are grown: Red Russian, Toscano, and Winterbor. Other varieties also grown include Lacinato and Vates for overwintering.

Most brassica greens are ready to start harvesting in 45 to 55 days for mature leaves, which is from transplant.

Greenhouse Production

All kale and collards are seeded into 128-cell Winstrip trays. They will grow for four weeks before transplant.

Direct Seeding

For baby/young leaves, kale is direct seeded at 0.8-inch spacing. See Crop Handbook: Leafy Greens (Direct Seeded) for more information.

Field Preparations

Collards and kale are transplanted in the bare-ground production system.

Transplanting

Kale and collards are planted using the Mechanical Transplanter planter at 12-inch in-row spacing.

Greens require a rate of 125 pounds of nitrogen per acre. All fertilizer is applied at planting.

Earliest date for transplanting in central Kentucky is March 10, and latest for outdoor field production is August 20. Plants can be overwintered with row cover or in a high tunnel. Late-fall plantings are recommended in early September.

Collard and kale transplants in the greenhouse are often easy to identify, even as young seedlings.

Lacinato kale is also known as Toscano, Tuscan, or dinosaur kale.

CROP HANDBOOK: COLLARDS AND KALE

Family: *Brassicaceae*

Crew members harvest kale and collards as individual leaves and then bunch them.

Cultural Practices

Insect pests, including aphids, imported cabbageworm, cutworm, flea beetle, and harlequin bug, frequently attack kale and collards. The greens are netted with 47- to 60-gram ProtekNet netting when flea beetle and harlequin beetle pressure is strong to maintain blemish-free leaves. Hoops are placed over plants to keep the net from touching the plants, as pests may still feed through the netting when it is in contact with the leaf surfaces. During wet periods, *Alternaria* can become a disease issue and is managed with copper.

Harvest

Kale and collards are harvested by hand, but a lettuce field knife is used in the field for trimming cut ends.

Harvest begins when the plants reach near-mature size, with numerous leaves well developed. The largest leaves are always harvested first, usually on the outer rim of the plant. Leaves are pulled off as close to the base as possible in order to leave plenty of stem for bunching.

Curly kale plants can also be harvested en masse. The plant is faced and both hands are placed on top of the leaves just outside the center growth point. Stems are grabbed at the base and yanked in one downward motion. Workers can easily grab four to eight stems in one motion with this technique.

Curly kale is grabbed below the smaller leaves on top, which are left to continue growing. Leaves are torn with two handfuls.

CROP HANDBOOK: COLLARDS AND KALE

Family: *Brassicaceae*

After bunching eight to 10 leaves, ends are trimmed with a lettuce knife.

Collard bunches usually have six to 10 leaves per bunch. Larger kale, like Winterbor and Red Russian, likewise get six to 10 leaves per bunch; smaller leaves, like those of Lacinato, may need 10 to 12 for a similarly sized bunch. Rubber bands or twist ties may be used for bunching. The leaves are all faced in the same direction, and the lower leaf margins are aligned. This will allow the tie or band to be placed as close to the leafy part as possible, leaving a stem below as a handle to grab. Cut ends are trimmed with a lettuce field knife to even the cut end. When placing bunches in the bin, stack vertically with stems pointing up for maximum pack efficiency.

Plants are cleaned during harvest. Any leaves that are yellowing, browning, or have insect damage are removed from the plant and tossed aside. Cleaning the plants reduces disease pressure and makes subsequent harvests easier.

Yield

Kale yields an average of 0.4 bunches per row foot.

Collards also average 0.4 bunches per row foot.

In CSA shares, kale and collards are rotated to provide greens six to eight weeks out of the year.

CROP HANDBOOK: COLLARDS AND KALE

Family: *Brassicaceae*

Bunched greens are washed with the bubbler and then counted into dark-green bins.

Post-harvest Handling

Kale and collards are washed in a dunk tank. A bubbler will help to agitate leaves to dislodge dirt and any insects. These crops are best counted and loaded into dark-green bins. Bunches of greens are laid down flat in bins, with stems pointing to the outside of the bin in alternating layers.

Items are counted, with the number of bunches packed per bin being consistent for every bin. Depending on the size of leaves, 12 to 20 bunches of greens can be packed in a bin at a time.

Storage

Kale and collards are stored at 32°F.

After the wash and pack, bins are covered with plastic pallet covers to trap moisture. Brassica leafy greens can remain in cold storage for 10 to 14 days after harvest.

Bunched Red Russian kale.

Bunched Winterbor curly kale.

CROP HANDBOOK: CORN

Family: *Poaceae*

Varieties

Sweet corn varieties at UK-CSA are sh2, or supersweet types. When other types are grown (synergistic or popcorn, for example), the different varieties are spaced apart at a minimum of 300 feet from one another, or their maturity dates need to be staggered by 12 days or more to prevent cross-pollination.

Sh2 varieties change frequently. Varieties that have done well include Catalyst, American Dream, SS3778R, SS2742, and Xtra-Tender 3473. Popcorn is a specialty corn grown at UK-CSA. Robust Yellow has performed well.

Sweet corn matures in 69 to 77 days. Popcorn matures in 110 days. Both days to maturity are from direct seeding.

Field Preparations

Corn is planted in the bare-ground production system. Since corn is not weed competitive, it is important that fields have undergone three to four passes of the stale seedbed cultivator prior to seeding.

Direct Seeding

Corn is direct seeded using the MaterMacc VegiMacc vacuum seeder.

Seed plate 36, 4.5 is used for all corn varieties. Optimal corn spacing is eight to nine inches in row. However, due to historic variability with germination, earliest corn is seeded at 3.9 inches and thinned to eight to nine inches. The variability is likely the result of cool soil temperatures for the earliest corn plantings. Corn requires a minimum soil temperature of 65°F for good emergence, but optimal temperatures are 80°F to 90°F. Early May seeding does not reliably get these temperatures. By middle of May, soils are reliably in the range of 68°F to 78°F. Therefore, on earliest seedings, check soil temperatures and err on the side of overseeding. When soil temperatures are higher, corn can be seeded at lower density. The MaterMacc VegiMacc sprockets for closer spacing of 3.9 inches are 22-21. For larger 7.8-inch in-row spacing, the sprockets are set at 12-23.

Approximately 10,000 seeds are required for five beds of corn, which is 3,000 row feet when seeded at the closer spacing.

Sweet corn and popcorn all require a nitrogen rate of 120 pounds per acre. All fertilizer required is applied at seeding.

Cultural Practices

When corn is seeded at 3.9 inches, it must be thinned to eight to nine inches. Within a week of emergence, workers walk each row with a scuffle hoe and remove any plants that are too close to achieve the correct spacing. The plants are

Corn is direct seeded with the MaterMacc VegiMacc.

Corn is finger weeded when plants are four to eight inches tall.

Family: *Poaceae*

sliced at the soil surface with a quick back-and-forth motion.

Corn is basket weeded and then finger weeded weekly when it is four to eight inches tall.

Corn needs to be monitored for worm pressure. There are two primary worm pests that impact our sweet corn: corn earworm and European corn borer (ECB). To monitor for these worms, trapping nets are mounted on a T-post at either end of the field starting in May, or when earliest corn is producing fresh silks. Monitoring ceases when fresh silks have dried.

Heliothis traps, made of collapsible mesh with a removable pouch for easy counting of insects, are used. The bottom net opening should be at the same height as the corn silks for proper trapping. Each net holds a lure for one of the two types of corn pests. For European corn borer, lures for both ECB I NY strain and ECB II IA strain should be used. The lures last around two to four weeks, so swapping out lures for new ones may be needed. Workers wear a new pair of nitrile gloves when handling each lure to prevent any cross contamination between lures. The net trap is checked one or two times per week for pest pressure.

When the earworm or borer moths are being caught, the crops will benefit from a protective measure. For ECB, five moths caught in a week during silking is a threshold to spray. When these pests are present, they burrow through the corn

A Heliothis trap is mounted on a T-post at the cornfield edge. The lure attracts the moths, and they will be trapped in the upper pouch.

A Heliothis trap, seen at top left, opens at silk height. In foreground, a worker harvests ears into red buckets.

husks in the middle of the ear, which ruins the entire ear. Alternatively, instead of monitoring, any corn at V6-V8 growth stage, about four to six weeks after emergence and before reaching 24 inches in height, are sprayed with a pesticide formulation derived from a parasitic fungus called *Beauveria bassiana*. Only one spray of *Beauveria bassiana* per planting is required.

For corn earworm, a different tactic is employed. Corn ears can individually be treated with either a Bt pesticide or Neemix 4.5 pesticide mixture using a Zea-later applicator. The Zea-later dispenses a predetermined amount of product (about one milliliter) using an easy trigger handle. A worker needs to wear waterproof pants and boots as well as gloves when using the Zea-later. The 32-ounce bottle can be mixed with the pesticide and dilution agents like Golden Pest Spray Oil and water.

To use the Zea-later properly, timing is critical. The Zea-later application should occur two days following full silk emergence, and the silks may be starting to turn brown at this time. However, the silks cannot be fully brown or the application will be too late. If no earworm moths are caught in the traps at this window, the Zea-later application can be skipped. To dispense the pesticide, the nozzle of the handheld Zea-later applicator is pressed into the tip of the corn ear where the silks

Corn silks fully emerged and beginning to brown are ready for Zea-later application.

Family: *Poaceae*

Zea-later application to corn ear tip.

are emerging. The trigger is depressed to dispense the measured amount per ear. Only ears that are full should get the pesticide application. This is usually only one ear per plant, though sometimes two ears on a plant may need to receive the Zea-later application.

Two other pests are sap beetles and Japanese beetles. Both are a nuisance but do not cause significant damage. They will be knocked off during harvest and washing.

In windy conditions, corn is at risk of lodging or falling over. Lodged plants may recover, but some will not produce any harvestable ears.

Sometimes corn smut is observed on ears in the field. Smut is rare and considered a delicacy for some cuisines. These ears are culled from the harvest.

Some lodged plants will not recover.

Family: *Poaceae*

Harvest

Sweet corn is harvested first thing in the morning on the day it is handed out, in order to minimize the conversion of sugars into starches. However, the supersweet sh2 varieties do very well in storage and are slower to convert to starch than other types of sweet corn.

Popcorn is harvested after the stalks have completely dried and turned brittle.

Workers begin harvest on the same side of the field, with each worker responsible for one corn row. Workers carry a few red buckets to hold harvested corn ears. For quick harvest, each ear is grabbed and twisted firmly while pulling down to dislodge the ear from the stalk. Any extra organic matter from base of the ear is broken off. When buckets are filled, workers carry them straight to the drive row edge of the field to be picked up later. Contents of buckets are dumped into larger harvest bins that have been laid along the outside edge of the field. Workers are advised to wear long sleeves to prevent skin irritation from the stalks.

Corn smut on an ear.

CROP HANDBOOK: CORN

Family: *Poaceae*

Yield

Sweet corn yields are 0.5 to 0.7 ears per row foot. Popcorn yields similarly, at 0.53 ears per row foot.

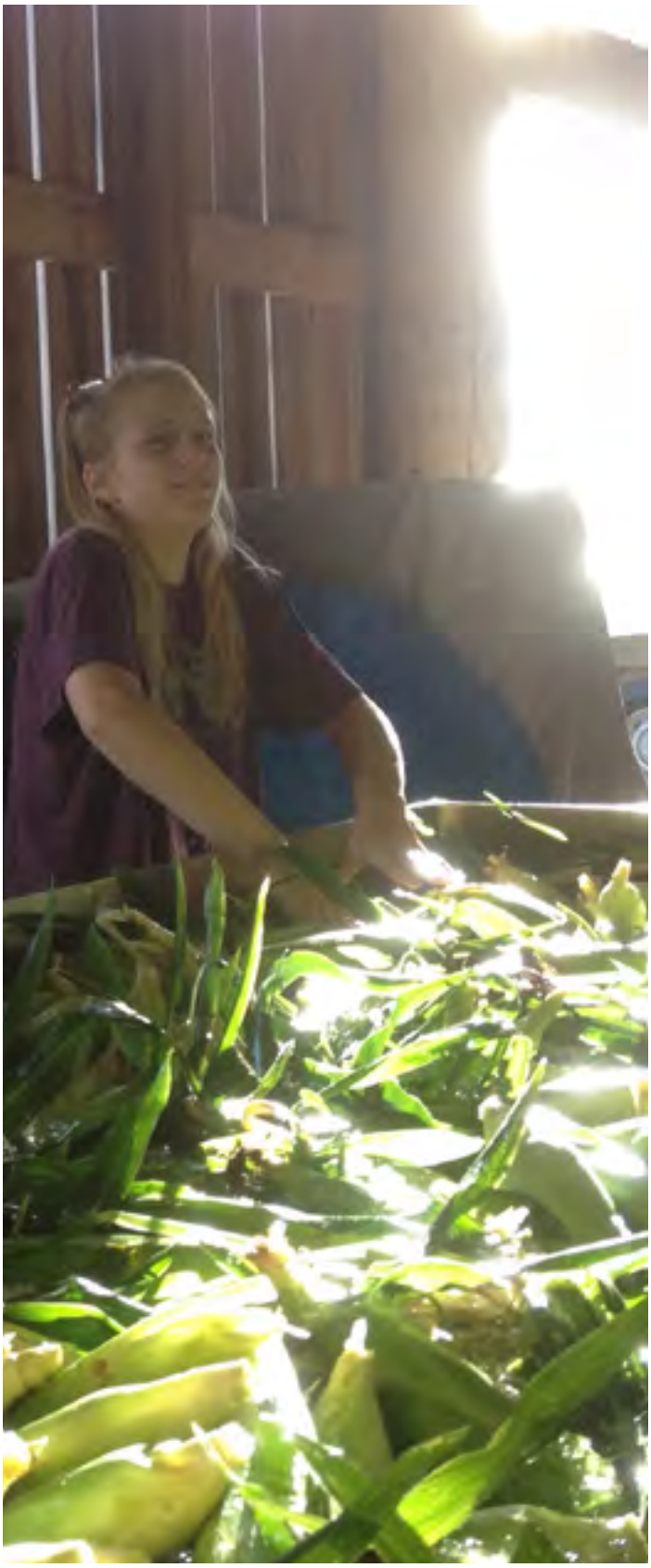
Harvest bins are lined up down the drive row so harvesters can empty corn into them from their red buckets.

Early-morning sweet corn harvest fills the harvest wagon and is taken back to the packing shed.

Popcorn is harvest ready when the stalks are completely dry and brittle.

CROP HANDBOOK: CORN

Family: *Poaceae*



Sweet corn is dunked in an ice bath for hydrocooling.

Corn is one of the more land-intensive crops. Therefore, plantings are limited to one acre in total. Each planting for a share takes half of a one-third-acre field. Sweet corn is usually distributed four to five times per year. The last corn planting is reserved for popcorn. Popcorn is a specialty crop and will usually be distributed once. Occasionally, popcorn stores into May and is included with the first shares of the year. Popcorn is also given out as a bonus item for Thanksgiving boxes.

Optimal number of ears per share is four to six. For popcorn, offering two to four ears at a time is sufficient.

Post-harvest Handling

The primary focus of post-harvest processing for sweet corn is to keep the product cool. In midsummer, corn is dunked in an ice bath in the dunk tank prior to being counted and stored. The purpose of the ice bath is chilling the corn more than washing it, since they are chilled with the husks still covering the ears. The process of dunking also allows for sorting again to check for worm holes on the sides of the ear that indicate European corn borer damage. These ears are not marketable. Some corn earworm damage is tolerated, and CSA members are advised to chop off corn tips if they are worried about finding a worm at the tip of the ear. The ear is still good even when an earworm may have found its way in. When corn is properly treated with Zea-later application, corn earworm control is high.

Corn ears are counted into dark-green bins. Around 75 to 80 ears can fit into one bin.

Popcorn must be cured in a dry, warm environment before being distributed. Ears are placed in a single layer on unused benches in the greenhouse to dry for two weeks. Popcorn will not pop right off the stalk; it will benefit from multiple weeks in storage prior to popping to dry out more. While the cure time of two weeks will help, popcorn will benefit from four weeks or more in storage. This timeframe makes popcorn an ideal crop around Thanksgiving.

The curing and storage environments are monitored for mice, as this pest can easily decimate a popcorn harvest if they find it.

Family: *Poaceae*

Storage

Sweet corn is stored for a minimal amount of time at 32°F. At UK-CSA, sweet corn is in the cooler for about six hours before being delivered to customers.

Popcorn, once cured, is counted and stored in blue bins when being handed out soon for the CSA. For long-term storage, ears are kept cool at 55°F in lidded, plastic totes. Dried husks are removed for long-term storage.

Bicolor sweet corn, at top left, and yellow sweet corn, top right. Bottom, corn husks are kept on ears at CSA distribution.

CROP HANDBOOK: CUCUMBER

Family: *Cucurbitaceae*

Varieties

Both slicing and pickling cucumber varieties are grown. Both open-pollinated and hybrid cucumber varieties have performed well. Slicing varieties grown include Cobra and Marketmore 76. Pickling varieties grown have included DeliStar, H-19 Little Leaf, and Boothby's Blonde heirloom.

Cucumbers mature in 58 to 63 days from direct seed.

Greenhouse Production

Cucumbers are hand-seeded into 72-cell Winstrip trays. They only require three weeks in the greenhouse, as they are fast growing and will get leggy quickly. However, direct seeding is the preferred production method.

Field Preparations

Cucumbers are fast growing and short-lived due to disease and insect pressures. For successful establishment, they are grown on black plastic mulch beds and row-covered at time of planting. Plastic beds are cultivated several times prior to planting. Each field holds six or seven beds for summer squash, zucchini, and cucumber combined in one field, spaced at least seven feet or eight feet apart respectively.

Cucumbers require 120 pounds of nitrogen per acre. Granular fertilizer is applied at time of plastic laying.

Direct Seeding

Cucumbers are direct seeded into the plastic mulch. Holes are punched in the plastic with the water wheel setter, with two rows per bed top and 12-inch in-row spacing. Workers place two seeds in each hole and sweep soil on top to finish planting. To keep hands from getting muddy, one hand is kept dry and is only used for seeding, while the other hand does the soil covering.

Earliest planting date is May 5, and latest is July 1. Three plantings of cucumbers are made in succession, spaced about four weeks apart.

Cucumber seeds are placed in a tan tray on the water wheel setter. Workers drop one or two seeds into each dibbled hole by hand and cover with soil.

CROP HANDBOOK: CUCUMBER

Family: *Cucurbitaceae*

Cultural Practices

Cucumber beds are covered with row covers at time of seeding. Row covers should have a small amount of slack to allow for cucumber growth underneath. Row covers are removed once plants are flowering for pollination. Cucumbers are hand-weeded and thinned in the holes at time of uncovering, and then the plastic-covered beds are cultivated before the vines spread past the bed edges.

Cucumbers are attacked by cucumber beetles and squash beetles. Once row covers are removed for pollination, Kaolinite clay is sprayed on the leaves to deter insect feeding.

Powdery mildew and downy mildew also occur frequently on cucumbers. Fungicides are rarely applied, since plants are so fast growing and short-lived.

While cucumbers can be trellised for easier harvest, it is not worth the labor investment to install and manage the trellis since cucumbers are so short-lived. In a different growing environment, like a high tunnel, a trellis is beneficial.

Harvest

Cucumbers are harvested three times per week—on Mondays, Wednesdays, and Fridays—on the same schedule as summer squash and zucchini. Fruits are harvested using small harvest knives to cut the fruit at the stem from the plant, or they can be pulled from the stem by hand. Two harvesters walk on either side of each bed. Slicing cucumbers are harvested when seven to 10 inches long, and pickling types are picked when three to five inches long. Cucumbers are ready when filled out

Example of cucumbers grown on a trellis.

Workers harvesting cucumbers search through vines and place cucumbers into red buckets.

Family: *Cucurbitaceae*

evenly the length of the fruit. Cucumbers that have puckering or tapering at ends are culled. Any oversized cucumbers are also culled. Cucumbers are placed into red buckets or harvest bins, and full buckets are carried to the edge of the field for pick up by the harvest wagon.

Yield

Slicing cucumbers yield 0.5 to 1.0 fruits per row foot; pickling varieties yield 0.45 to 1.0 fruits per row foot.

Cucumbers are included in CSA shares eight to 10 times per year and are a staple crop. Slicing cucumbers are given out for two-thirds of these distributions, and pickling cucumbers are given out in the last third of the season. CSA members receive two to four slicing cucumbers or four to six pickling cucumbers for each share week.

Post-harvest Handling

Cucumbers are washed in the brush washer. After washing, cucumbers are sorted and counted into light-green bins. Bins are labeled with the number per bin.

Buckets are loaded on the harvest wagon and taken to the packing shed.

Cucumbers are washed on the brush washer and then counted into light-green bins.

CROP HANDBOOK: CUCUMBER

Family: *Cucurbitaceae*

Storage

Cucumbers are optimally stored at 50°F to 55°F. No plastic pallet covers are required over the bins.

Cucumbers can be stored for one to two weeks. Boxes of 20 pounds of cucumbers can be sold for pickling when there is a surplus.

Bulk box of cucumbers, bottom, and four pickling cucumbers for a CSA share distribution, top right.

CROP HANDBOOK: EGGPLANT

Family: *Solanaceae*

Varieties

The standard purple globe varieties grown include Galine and Slim Diamond.

Specialty eggplants include Asian types or Italian types with unique coloring or variegation. Dancer yields similarly to Galine. Nubia is striped pink and white, but yields are significantly less. Slender Asian types like Orient Express, Orient Charm, and Ping Tung Long likewise have reduced production compared to globe eggplant.

Eggplants mature in 65 to 68 days from transplant.

Greenhouse Production

Eggplant starts in 162-cell Winstrip trays with two or three seeds per cell. They are placed on a heat mat at 80°F to 85°F until germination and then removed from the heat mat.

After three weeks, or once seedlings develop true leaves, eggplants are potted up to 50-cell Winstrip trays.

Transplants are ready after seven weeks. They are hardened off gradually during the seventh week. During hardening, flats are covered with row covers on the hardening tables or wagons to prevent flea beetle damage prior to transplanting.

Field Preparations

Eggplant is grown on black plastic mulch or aluminized plastic mulch, with teff or millet living mulch mixed with clover in between the beds.

Globe eggplants are the standard variety grown.

Eggplant requires 120 pounds of nitrogen per acre. Two-thirds of the fertilizer requirements are applied pre-planting, and one-third is delivered via fertigation after eight to 10 weeks of growth.

Transplanting

Eggplant is transplanted in the field using the water wheel setter in two rows per bed at 15- to 18-inch in-row spacing.

Earliest planting date in the field is May 1–10. A second succession can be planted three to four weeks later, around June 5–10. June 15 is the latest recommended planting date.

All eggplant is planted later to reach maturity in August, which is the planned time for eggplant to be included in CSA shares.

Living mulches are seeded in eggplant fields.

Eggplant is transplanted using the water wheel setter.

CROP HANDBOOK: EGGPLANT

Family: *Solanaceae*

Cultural Practices

Eggplant is highly susceptible to flea beetle damage. Plants are netted with 47-gram ProtekNet netting immediately at time of planting. When netting is not used, plants are planted into aluminized plastic mulch.

Once plants begin to flower, netting or covering is removed for pollination. At this growth stage, the eggplant can withstand some flea beetle damage. The row cover is not replaced, as continued pollination is desired for harvesting over multiple weeks.

Common eggplant issues include scarring on the exterior flesh, which may be a result of thrip damage; sunscald; and anthracnose. Excessively scarred fruits are culled. Copper is applied for protection against anthracnose.

Harvest

Eggplants are harvested twice a week, on Monday and Thursday mornings. Eggplants are ready when six to seven inches in length for globe types, and 10 inches for slender Asian varieties. The normal length of pruning shears is eight

Flea beetle damage on leaves, left, can stunt plants when damage is severe on young plants. Netting, right, protects young plants.

Purple eggplant flowers require insect netting or row covers to be removed for pollination.

Family: *Solanaceae*

inches and serrated harvest knives are seven inches long, so harvesters can compare length of eggplant to their harvest tools for reference.

Eggplants should have a sheen to their skin. Coloring should be deep purple for standard types. Eggplants are firm fruits but have a small amount of give to their skin. When lightly pressed on the outside skin, a small indentation from one's thumb should bounce back. Eggplants should be neither rock-hard nor have a dull appearance. Plants usually yield only one or two mature eggplants at any one time.

Eggplants are removed from the plant by hand with pruners or small serrated knives. Stems are very hard, so tools must be sharp. Eggplants are grabbed from the bottom, as the green calyx around the stem has small spines that will injure hands unless gloves are worn. A small stem of one half-inch to one inch is left on the fruit. Harvested eggplants are placed in red buckets or brown harvest bins. The bins are carried to the outside field edge for pick up.

During harvest, plants are cleaned by clipping off any overmature, damaged, diseased, or soft fruits and discarding them in the drive rows to be removed from the fields.

Yield

Globe eggplants yield on average 0.15 to 0.5 fruits per row foot per week.

Eggplants are given out in CSA shares six to eight times. Sometimes eggplant is a choice item, mixed with peppers as part of the member's choice for that week, or alternated weekly with peppers or cucumbers in the share. Ideally, two eggplants are distributed each week they are included in CSA shares.

When harvesting eggplant, workers must look under the plant canopy to find fruits. Use pruners to clip stems.

Buckets of Dancer eggplant, an Italian type.

CROP HANDBOOK: EGGPLANT

Family: *Solanaceae*

Post-harvest Handling

Eggplants are washed using the brush washer. Undersized fruits are sorted out. Many eggplants develop "noses," but these are still retained for the CSA shares, as fruit quality is unaffected by novel appearances.

After washing, they are counted into light- or dark-green bins, and each bin is labeled with the final count. Bin labels are placed on the short side facing outward when bins are stacked.

Storage

Eggplant should be stored similarly to peppers, at 45°F to 55°F. Plastic pallet covers are placed over stacks of bins. Shelf life is one week.

Eggplants are washed on the brush washer, sorted, and counted into green bins.

Washed Ping Tung Long eggplants.

Noses on eggplants are whimsical and do not affect fruit quality.

CROP HANDBOOK: FENNEL

Family: *Apiaceae*

Varieties

Fennel can be grown as both leaf and bulb types. For bulb fennel, Preludio is used and is available in both raw and pelleted seed. For leaf fennel, Grosfruchtiger is planted and used as an herb. The bulb fennel can also be given out with the fronds, which gives customers two products in one.

Leaf fennel is harvest ready in 50 days, but bulb fennel requires 65 to 70 days to reach mature size from transplanting.

Greenhouse Production

Fennel is seeded into 128-cell Winstrip trays. Greenhouse growth takes seven weeks.

Transplanting

Fennel does best in fall. Fennel is transplanted in July for a September harvest. In-row spacing is nine inches when using the Mechanical Transplanter planter, though fennel can also be grown at six-inch spacing.

Fennel requires 100 pounds of nitrogen per acre. All fertilizer required is banded at planting.

Baby fennel bulbs a few weeks after being transplanted.

CROP HANDBOOK: FENNEL

Family: *Apiaceae*

Fennel bulb harvest.

Cultural Practices

Excessive moisture can cause rot on the base of bulbs. Delayed harvest can also be detrimental to the crop, as quality decreases. Crops are monitored for rot, and bulbs may be harvested early or slightly small to prevent further damage.

Harvest

Fennel leaf is harvested like a bunched herb. A small knife is used to cut fronds above the lower growth point. Leaves are banded together with a small rubber band. Ends are trimmed even with a small knife. See the **Herbs** section for more information.

Bulb fennel is cut first with a lettuce field knife or pruners at the base to separate the bulb from the thicker root. Cuts are made below the outermost layer. If there are any soft or browning spots on the outer layers, these outermost layers are peeled off. If the browning is deeper than one layer, it is not worth it to continue peeling off layers. The bulbs with fronds attached are attractive but take up more storage space. For bulb only, clip the fronds one half-inch above the bulb top with a small knife.

To harvest a bulb, the bulb is pushed away to expose the root for clipping.

CROP HANDBOOK: FENNEL

Family: *Apiaceae*

Fennel bulbs with trimmed roots are piled and ready for loading into bins.

Yield

Fennel bulb yields 0.75–1.0 bulbs per row foot of plants.

Fennel is a specialty crop that is not grown every year. Fennel is included in shares one or two times a year but is usually a choice item with other items as alternates. Members receive one to two bulbs at a time.

Post-harvest Handling

Leaf fennel does not need washing.

Fennel with fronds attached are washed using the rinse conveyor or by doing a quick spray on the bunched washing station. Bulbs only can be washed in the brush washer or rinse conveyor.

Bulbs are counted individually and stored in light-green bins. Fennel with fronds still attached are counted and stacked in alternating directions into light-green, dark-green, or green 1.75-bushel bins.

Fennel is the peacock of the vegetable world; its fronds are showy and take up a lot more space than the bulb itself.

CROP HANDBOOK: FENNEL

Family: *Apiaceae*

Storage

Leaf fennel is stored like most herbs, upright in a jar with one inch of water covering the bottom stems. It can be held in the cooler at 32°F.

Fennel bulbs and fronds should be kept at 32°F. Plastic pallet covers are placed over the bins for maximum moisture retention. Any fennel with fronds attached that is not given out or used promptly has the fronds clipped the next day, and the bulb will hold in storage for two to three weeks for a later distribution.

Fennel bulb with fronds.

CROP HANDBOOK: CUT FLOWERS

Family: Various

Varieties

Annual flowers chosen for cut-flower production at the CSA you-pick focus on those that are easy to grow, with prolific and long-lasting blooms.

Favorite cut-flower types include the following: ageratum (Tall Blue Planet); bachelor's buttons (Florist Blue Boy); calendula (Alpha and Zeolights); celosia (Pampas Plume, Chief Mix, and Eternity Improved); cosmos (Double Click Mix); gomphrena, also known as globe amaranth (Strawberry Fields); sunflowers (Jade, Teddy Bear, Starburst series, ProCut series, and Sunrich series); helipterum, also known as everlasting daisy (Pierrot White); marigold (Giant Orange and Giant Yellow); scabiosa, also known as pincushion flower (Black Knight, Sternkugel); statice (Seeker Mix); strawflowers (Monstrosum Tall Mix, Apricot/Peach Mix); tithonia, also known as Mexican sunflower (Torch); verbena (*Verbena bonariensis*); and zinnia (Benary's Giant Mix, Zinderella Peach).

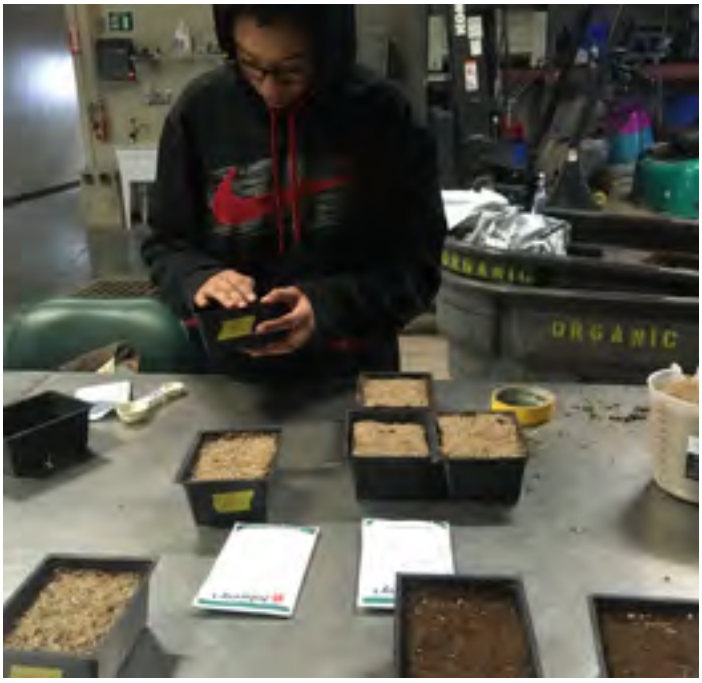
Other varieties occasionally grown include amaranth, Queen Anne's lace, false Queen Anne's lace, asters, honeywort, drumstick flower, Chinese forget-me-not, dahlia, eucalyptus, matricaria, flowering tobacco, nigella, ornamental grass, phlox, poppies, and snapdragons. While some flowers are perennials or tender perennials in Zone 6b, all the cut flowers are managed as annuals.

You-pick is one of the perks of CSA membership. Flowers are the most popular you-pick item.

CROP HANDBOOK: CUT FLOWERS

Family: Various

Planting crops by height prevents shading any of them out.



Seeds are started in individual flats for germination and covered with vermiculite.

Peredovik sunflowers are grown in the field to border the edges of sweet corn fields. These sunflowers attract beneficial insects and are also harvested once for inclusion into CSA shares.

Varieties are chosen with a range of maturity dates to provide a large harvest window. Earliest maturing flowers, like calendula and some sunflowers, are ready in 50 days, while others may take 100 days or more. Peredovik sunflowers mature closer to 100 days.

Greenhouse Production

While some flowers do best when direct seeded, all flowers for you-pick are transplanted.

Flowers that are in the greenhouse for more than six weeks are seeded into six-inch-by-four-inch L-Series Landmark plastic flats. Unless otherwise indicated, all flats are covered with vermiculite in a thin layer and placed on the mist bench in the greenhouse. Quickly growing flowers, like cosmos and sunflowers, are seeded directly into 72-cell Winstrip trays and do not require misting. Flowers that require germination temperatures above 75°F are placed on a heating mat.

CROP HANDBOOK: CUT FLOWERS

Family: Various

Flats are placed under misters in the greenhouse until they fully germinate.

Greenhouse instructions for the standard cut-flower varieties are given in Table 1.

Once flowers germinate, they are removed from the misting bench to prevent waterlogging. When the seedlings have the first set of true leaves, flowers are potted up to 128-cell Winstrip trays. After three weeks of growth in the 128-cell trays, any flowers that outgrow the 128-cell trays and require a larger cell can be potted up a second time into 72-cell Winstrip trays.

Field Preparations

Annual flowers are planted into black plastic-mulched beds.

Flowers may have small differences in nitrogen requirements, but since the flowers are all mixed in the same field, a standard nitrogen requirement rate of 100 pounds per acre is used to calculate fertilizer applications for all cut flowers. Fertilizer is applied pre-planting at time of plastic mulch installation. No fertilizer is applied for Peredovik sunflowers in the field.

Table 1. Cut-Flower Greenhouse Production Notes

Flower	*Days to Germination*	*Germination Temperature*	*Seeding Instructions*	*Transplant Age (Weeks)*
Ageratum	7-10	75°F-80°F	Do not cover with media, light vermiculite only	8
Bachelor's Button	7-14	60°F-65°F	1/4" deep, cover lightly	6
Calendula	6-14	70°F	Darkness required, cover completely	8
Celosia	8-14	70°F-80°F	Do not cover with media, light vermiculite only	8
Cosmos	7-10	68°F-72°F	Barely cover, keep moist	5
Gomphrena	5-14	70°F-78°F	Cover lightly, keep moist	8
Helipterum	14-21	65°F-70°F	Cover lightly, keep moist	8
Marigold	4-7	75°F-80°F	Cover lightly	5
Scabiosa	10-12	65°F-70°F	Barely cover with vermiculite	8
Statice	5-14	70°F	Barely cover with vermiculite, light required	8
Strawflower	7-10	70°F-75°F	Do not cover with media, light vermiculite only	8
Sunflower	7-14	70°F-75°F	Cover completely	4
Tithonia	7-14	70°F-85°F	Barely cover	6
Verbena	14-28	60°F-86°F	Stay on dry side	12
Zinnia	3-5	80°F-85°F	Cover, keep moist	5

CROP HANDBOOK: CUT FLOWERS

Family: Various

Transplanting

Cut flowers are transplanted at 12-inch in-row spacing, in two rows per bed. They are transplanted after the danger of frost, in early May.

Flowers are transplanted in ascending order of height to reduce plant shading or overcrowding from larger growing varieties.

Cultural Practices

In general, cut flowers do not have many pests or diseases issues. Cut flowers are a great benefit to the farming system as they attract a wide range of beneficial insects and pollinators. Some cut flowers, like zinnias and dahlias, are susceptible to powdery mildew. They are mowed or removed when production declines.

Sunflowers, due to their height, are staked if needed. Tobacco stakes are placed every 10 to 20 feet on either side of the bed. Twine is wound around the outside of the stakes to hold the stems upright.

Cut flowers are planted in a field specially designated for you-pick for CSA members. This field receives a high volume of foot traffic. A sturdy living mulch, like millet and clover, is established in the aisles between the plastic beds shortly after planting. The living mulch is managed weekly with mowing by a BCS walk behind tractor and flail mower.

When sunflowers have finished sending up new flower heads, the stalks are removed, as they will begin to fall over. A second succession of sunflowers is direct seeded into the cleared holes in the plastic beds.

Sunflowers are staked as a group with twine to hold them inside the bed perimeter.

A living mulch is established between flower beds soon after transplanting.

CROP HANDBOOK: CUT FLOWERS

Family: Various

Sunflowers broadcast on a field edge allow for a one-time harvest for 250 CSA members.

Harvest

You-pick flowers are harvested by CSA members using hand tools. Pruners and small serrated knives work the best. Stems are cut individually close to their base or branching point. Cut stems are best placed at time of harvest into a bucket with one inch of water to keep them fresh.

Sunflowers harvested for the CSA shares are cut using pruners or loppers. Stems two feet in length are kept attached. Extra leaves are removed from the stems. Stems are placed in five-gallon buckets with a few inches of water at the base. Larger plastic totes and bins may also be used to hold sunflowers.

Yield

Since cut flowers are only for on-farm you-pick, yield is not tracked. Poorly performing varieties are noted and not seeded in following years, as the priority is harvest abundance and long harvest length.

For CSA sunflower harvest, members receive at least two stems in their share.

Post-harvest Handling

Flowers are not washed. They are held in moist paper towels or in a jar or bucket with one inch of water to keep them fresh. Ends can be trimmed again at a 45-degree angle before they are placed in their final home or vase.

Harvested sunflowers are kept in buckets or totes with some water to keep them fresh.

Family: Various

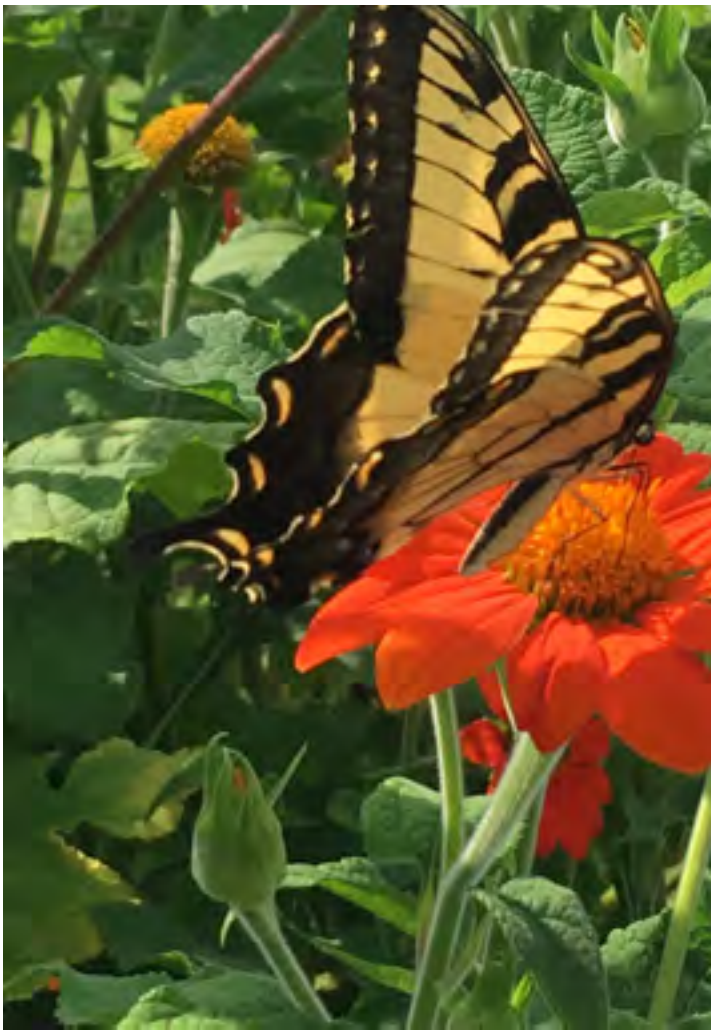
Storage

Flowers are not stored in coolers, as they are taken home or distributed immediately after harvest.

Clockwise from top left: A honeybee feeds on verbena; Zeolights calendula; A bumblebee on Chinese forget-me-not; Dara daucus.

CROP HANDBOOK: CUT FLOWERS

Family: Various



Clockwise from top left: Black Knight scabiosa; a butterfly on tithonia; Florist Blue Boy bachelor's buttons; snapdragons.

CROP HANDBOOK: CUT FLOWERS

Family: Various

Clockwise from top left: celosia; ageratum; Sternkugel scabiosa; Strawberry Lemonade sunflower.

CROP HANDBOOK: GARLIC AND ONION

Family: *Allium*

Varieties

Music porcelain hardneck garlic is the variety grown exclusively. This garlic has high storage potential, performs well in Kentucky, and has fantastic flavor.

Onion variety choice is dictated by latitude and corresponding day length. In central Kentucky, only intermediate day length onions can be grown, and options are limited. Many of the best storage onions are not suitable for Kentucky. Therefore, onion varieties are ones that are good for fresh eating and shorter-term storage. For yellow onions, Expression has performed well, better than Candy. For white onions, Sierra Blanca is reliable. For red onions, Cabernet or Monastrell are grown.

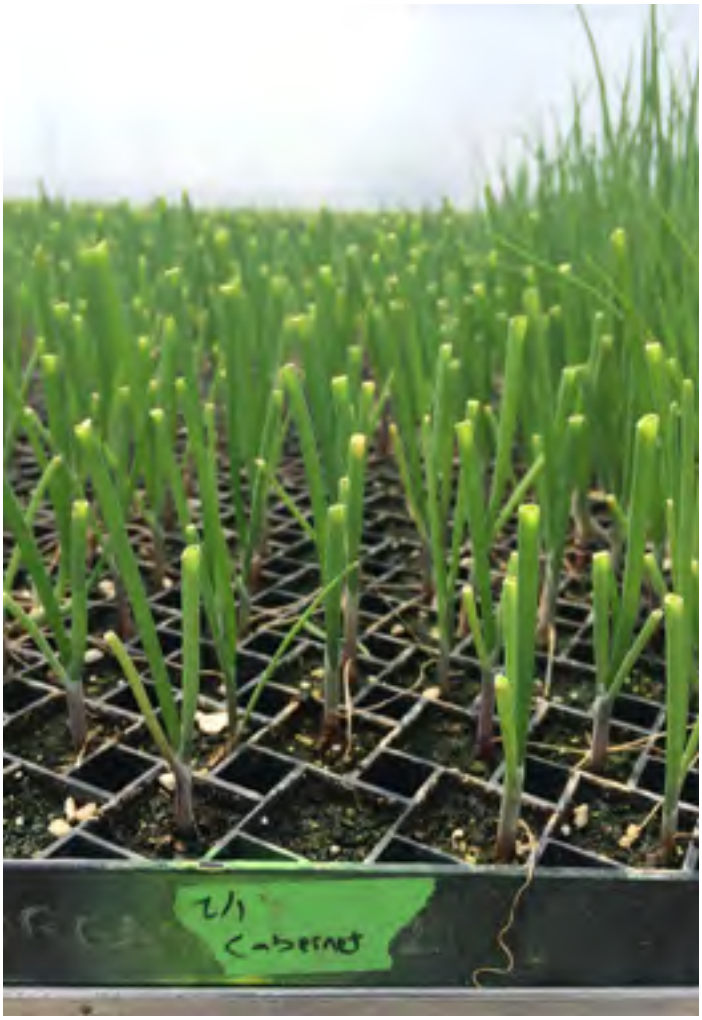
Garlic is one of the few crops that overwinters. This crop is in the ground for nine months, from October to June.

Onions are one of the first transplants of spring in early April and are harvest ready in mid to late July. Onions mature in 100 to 109 days.

Greenhouse Production

Garlic is direct seeded by hand in the beginning or middle of October. Onions will be started in the greenhouse in January in 162-cell Winstrip trays, with one seed per cell. Onion seed with NOP-compliant pellets is preferred. Using pelleted seed is the most reliable way to get even seeding in the greenhouse with only one plant per cell. Onions do not develop strong root systems readily and can be difficult to thin or pot up. Onions will grow for 14 weeks in their greenhouse trays.

After four to five weeks in the greenhouse, plants will be four to six inches tall. They will benefit from a "haircut." Scissors are used to trim one-third of the green leaves off above the growth point. One-third will be trimmed again four to six weeks later, if needed. These trims help the onion to put energy into its roots for better root ball development. This aids in easier planting. Weekly greenhouse fertigation for onions is recommended after eight weeks in the tray.



Onion transplants on left have been trimmed by a third.

Onion transplants ready to go in the ground.

CROP HANDBOOK: GARLIC AND ONION

Family: *Allium*

Field Preparations

Both garlic and onions are planted on plastic mulch. Plastic mulch-covered beds are installed by late September in anticipation of October planting. Beds for garlic and onions are installed at the same time. Onions are not transplanted until April of the following year, but installing the plastic-covered beds in the prior fall ensures that the crop can be planted in a timely fashion. Spring can be a difficult time to do field work due to soil moisture.

Both fields are planted with a rye-clover living mulch between the beds. This will allow the mulch to establish and overwinter, covering the soil and minimizing erosion. The living mulch may need to be mowed a few times in the spring.

Both garlic and onions require 75 pounds of nitrogen per acre. All fertilizer required is applied pre-planting, at time of plastic laying.

Transplanting

Both onions and garlic are planted on a three-row system on plastic mulch. Garlic is planted at nine-inch spacing in-row, while onion is done at 12-inch spacing. Based on research from Roxbury Farms, garlic performs best when planted on white plastic mulch rather than black; however, black can also be used. Onions are susceptible to thrip damage, therefore they are planted on aluminized plastic mulch. A heat strip in the middle of the plastic may help warm soils for these crops

Garlic is planted on white or black plastic mulch in fall. Crimson clover is sown as a living mulch and will be mowed at bloom in spring.

Onions are planted on aluminized plastic mulch in spring.

Family: *Allium*

Planting garlic by hand. Each clove is staged in each hole.

in early spring, but they perform equally well on both types of aluminized mulch.

Garlic is best planted in October, around October 5–15, for Kentucky. It can be planted as late as November, but it is better to get it in earlier. When garlic seed is planted by hand, individual cloves are broken apart from bulbs. The cloves themselves do not have be peeled, so this saves on labor expenditure. The water wheel dibblers or the hand seedbed roller with dibbles are rolled over the bed tops to punch holes at the proper spacing. A five-gallon bucket of loose cloves is carried along the bed as cloves are positioned in the holes for planting, and the planting crew follows behind. This ensures that everyone plants one clove into each hole and no one loses track of where they have already planted.

The flat bottom of the clove is pushed down and the tip or point of the clove is pointing up. The cloves are pushed with thumb and forefinger as far as possible down into the dibbled holes of the plastic mulch bed, and then the surrounding soil is swept with one's finger on top of it. The goal is to have as much soil above the tip of the clove as the clove is high. This translates into approximately one inch of soil above the clove, or workers pushing cloves as far down as the first or second knuckle on the forefinger.

If the soil is very dry, this process will be difficult. Soil moisture under the plastic is checked prior to planting. Irrigation lines can be run under the plastic, or holes can be dibbled in advance and allow rain to filter into the bed prior to planting to make this process easier. Small sections of rebar can also be used to open up holes in the soil for easier hand-planting.

Onions are transplanted using the water wheel setter. Tractor speed for planting three rows of onions is around 0.25 mph.

Garlic is planted on plastic mulch beds, three rows per bed. Living mulches are seeded in between the beds.

CROP HANDBOOK: GARLIC AND ONION

Family: *Allium*

Cultural Practices

Garlic will emerge before going into winter. A few hand-weeding passes of the garlic holes will be beneficial, particularly in spring as plants start to take off. Plants are monitored in May for the emergence of their flower stalks. These stalks will be very curly before eventually straightening and blooming. The stalks, also called garlic scapes, are removed from the plants prior to straightening and blooming. Workers walk the field and snap off each garlic scape at the base where it emerges from the garlic plant, and they place them into a tote or bucket. A lightweight buckets with a slit can be worn on a worker's belt to keep both hands free for quick snapping.

The garlic scapes may need to be harvested more than once if some of the plants are delayed in sending up their scapes. When the scapes begin to straighten, they will stand a foot above the plant height, so it will be obvious to spot those that may have been missed. Snapping off scapes concentrates the plant's energy in its final month into producing a larger garlic bulb. About one month after garlic scape harvest, check garlic for harvest readiness.

Garlic and onions can both be afflicted with botrytis in spring, which causes neck rot. In organic systems, applying a copper fungicide before major rain events in spring, as temperatures are in the 50°F to 60°F range, will help with prevention. Sprays are usually started in April.

While onions do not produce flower stalks like garlic, they can get overheated or trap too much moisture under the plastic as they begin to bulb out. If using plastic mulch as weed prevention, the plastic mulch is slit open between the rows of plants to bring in more airflow. This is typically done during

Garlic scapes are immature flower stalks. Once these emerge, they are snapped off from the plant.

Garlic scapes can be harvested into buckets. Buckets can be belt-tied for double-handed harvesting.

Family: *Allium*

During the last month of growth, garlic leaves begin to yellow.

the last month of maturation, if bulbs are beginning to press up underneath the plastic mulch. By dibbling a larger hole in the plastic at planting, this moisture and heat trap may also be avoided.

Harvest

Garlic and onions will give clues for crop readiness based on the decline of their visible leaves. The lower two leaves on garlic will yellow and brown as a first indication. It is helpful to dig up a few garlic bulbs about a month after harvesting garlic scapes to check for clove development and bulb size. There should be fewer than six wrapper layers to be removed before reaching the individual cloves. If there are more than six wrapper layers, the garlic may need more time for development.

Onion necks will begin to weaken as they near full growth. When pressing on the onion neck with two fingers an inch above the bulb, the leaves should readily give and "flop" backward. When around 50 to 75 percent of the necks can easily be pushed over (flopping), they are ready to harvest. At UK-CSA, harvest is begun at 25- to 50-percent neck flop, because it is a challenge to remove so many onions from the field in a timely manner. The onion harvest may take several days, and they cannot be harvested when there is rain or wet conditions. Slightly earlier harvest has also cut down disease incidence and post-harvest rots.

Place fingers an inch above bulb top and push to test for neck weakness.

Neck on onion has "flopped."

CROP HANDBOOK: GARLIC AND ONION

Family: *Allium*

Since both garlic and onions are grown on plastic mulch, a plastic lifter is used to get under the plants prior to harvest. This will loosen the plants at their roots and unearth the buried plastic edges at once. Plants are pulled out of the plastic and shaken to dislodge soil from the roots. Plants are stacked into piles for field processing. If it is a sunny day, plants can be left in the sun without damage for several hours. Both onions and garlic have their greens clipped prior to storage. Excessive green material prolongs the time needed for curing. About a forefinger's length of stalk, roughly two to three inches, is left above the bulbs as a neck. A pruner or a harvest knife is used to chop off the leafy material above this length. The roots are trimmed as well.

It is important to inspect the neck of the bulb at the time of harvest. Once the greens are clipped, there should be a solid mass of tissues that are green or white in color. In hardneck garlic, there is a center hard stem, which is not present in onions. If this interior neck is browning or desiccated, these plants are compromised. Compromised bulbs are moved to a cull bin. Knives or pruners used are promptly bleach sanitized so as not to spread any contamination to the next bulb that is processed.

Both onions and garlic are harvested by using a plastic lifter and then pulled into piles.

Trim greens off of garlic bulb at harvest, leaving a few inches of stem.

Left, garlic has neck rot and should be culled or given out fresh. Middle, garlic has mild discoloration at neck tissues. Curing can be attempted, but these are kept separate in the curing environment for evaluation. Right, garlic has a healthy neck and is ready to cure. Be sure to sanitize harvest tools after trimming heads 1 and 2 as a precaution.

CROP HANDBOOK: GARLIC AND ONION

Family: *Allium*

A healthy onion neck.

Post-harvest Handling

Onions are not washed. After clipping greens and roots and shaking off as much soil as possible, they are transferred to the curing location. Garlic can be handled the same way as onions, or it can be washed in the rinse conveyor before being transferred to its curing location. Washed garlic will not require additional peeling prior to being market ready.

Both garlic and onions require one to three weeks of curing time, unless they are being distributed for fresh eating. Curing optimizes storage life. The ideal curing environment will be warm and dry. Harvested crops are not put in direct sunlight, as this can cause sunscald and compromise storage life. While a warm, dark room would be ideal, a production greenhouse is adapted to serve as a curing environment. To prevent sunscald, a shadecloth is draped over the crops. Crops are laid on benches in a single layer. Additional layers are created by stacking racks on top of concrete blocks. The curing area is condensed into two tiers. The final layer uses concrete blocks to elevate the shade cloth above the crops. Air flow is also critical. A large box fan is positioned at the end of the bench to blow air over the tops of crops. Curing takes one to three weeks. After this time, crops are sorted and counted into burlap sacks, wax boxes, or bins for holding.

Garlic that is not rinsed prior to curing, top, will have the outermost layer peeled off. Garlic that is washed in the rinse conveyor before curing, bottom, is already clean. Only roots may be trimmed at this point.

CROP HANDBOOK: GARLIC AND ONION

Family: *Allium*

Curing garlic, top, and onions, bottom, on racks that are stacked using concrete blocks. Onions and garlic are organized on curing benches by variety. All questionable items are kept on a separate bench.

Family: *Allium*

Curing onions under shadecloth.

Processing garlic by peeling soiled outer layer.

When being sorted, bulbs are inspected and felt for any soft sections, and if any are found, the bulbs are culled. If any visible juicing or foul smell is detected in onions, they are placed directly in the compost barrel.

Garlic can have its outermost soil-laden layer peeled off to reveal a bright white layer underneath. Onions may not need to be peeled, unless there are soft spots that need to be inspected. Onion layers can be peeled back until any damaged layers are removed. Peeled onions should be given out promptly as fresh onions.

Yield

Approximately 25 to 28 percent of the garlic harvest will be retained for next year's planting. The nicest, biggest garlic heads are set aside for this purpose. Garlic bulbs that are destined for seed are never refrigerated, as this can trigger growth prematurely after a false "winter" in cold storage.

Garlic yields 0.9 bulbs per row foot. A total of five beds of garlic are grown for CSA, along with two beds for garlic seed.

Onions produce about 0.45 to 0.55 bulbs per row foot. Yellow onions have the fewest culls.

Fresh garlic or fresh onions are a welcome addition to CSA shares when they first come out of the field in late June or early July. After curing, onions are given out six to seven more times, and garlic seven to eight times. Ideally, these items are in shares every two to three weeks. Weeks they are included in shares are staggered for optimal variety. Each time, two onions or two garlic heads are given out. When scapes are distributed in the early part of the season, members receive one bunch of six to 10 scapes banded together.

CROP HANDBOOK: GARLIC AND ONION

Family: *Allium*

Garlic scapes are weighed and bundled with a rubber band for distribution.

Family: *Allium*

Storage

In general, both cured onions and cured garlic may be stored at room temperature out of direct sunlight, however storage at 32°F will be beneficial to longer shelf life. Garlic that will be saved for seed should never be refrigerated and is kept at ambient temperature in the packing shed. Boxes, bins, or burlap sacks can be used for storage. Some air flow is beneficial. Garlic and onions that are fresh (not cured) are given out promptly and used within two weeks. They are best stored under refrigeration at 32°F until distribution.

Preservation

Garlic and onions can both be dried and ground as a powder. Garlic drying is hastened by slicing peeled cloves into halves or thirds before spreading in a single layer in the dehydrator. Garlic powder is given out in increments of 1.0 to 1.5 ounces, weighed into poly reclosable zipper bags.

The dried cloves are ground into powder and bagged.

Garlic cloves are cut in thirds before loading in the dehydrator.

Garlic scapes are bunched, banded, and piled into a bin for the CSA.

CROP HANDBOOK: GARLIC AND ONION

Family: *Allium*

Two cured garlic heads, trimmed and peeled for CSA shares.

Yellow onions, cured and ready for distribution.

CROP HANDBOOK: GINGER AND TURMERIC

Family: *Zingiberaceae*

Seed pieces laid out for pre-sprouting, turmeric on top and ginger on bottom.

Varieties

Bubba Blue and Peruvian Yellow ginger varieties have been grown. For turmeric, Hawaiian Red and Indira Yellow have been grown.

Bubba Blue ginger is high-yielding and low in fiber. Seed pieces are ordered in November. Only tissue-cultured seed is ordered to minimize risk of disease transmission. One pound of ginger or turmeric seed will provide around 10 to 15 seed pieces.

Mature ginger and turmeric are ready after 10 months. Baby ginger and baby turmeric are ready in 120 to 180 days. In zones 6a to 6b, most ginger and turmeric only reach the baby stage.

Greenhouse Production

Ginger and turmeric are pre-sprouted in a greenhouse starting in early February in order to be ready to transplant by the beginning of May.

Ginger and turmeric are rhizomes. The entire rhizome is termed a "hand." The "fingers" of the hand are separated by snapping or cutting with a knife. Pieces are placed atop two inches of evenly moistened potting mix in a shallow tray or bin. Seed pieces should not be touching. Each finger, or seed piece, is buried under one to two inches of media. The bins are placed on heat mats set at 72°F to 85°F and kept evenly moist. Overwatering can cause rot.

Signs of initiation occur when nodes begin to swell and push out. Initiation may take four to eight weeks. Shoot emergence above the media in the trays should occur within six to 10 weeks. Once shoots have emerged one to two inches above the media, this is the early growth stage. At this stage or later, they can be transplanted.

Initiation with node swelling.

CROP HANDBOOK: GINGER AND TURMERIC

Family: *Zingiberaceae*

Transplanting

Ginger and turmeric pieces are transplanted once soil temperatures are at 55°F or above. Shoots and initial roots are kept intact as much as possible. Hilling is required for ginger, since the rhizomes grow upwards. The planting area is started by digging a trench six to eight inches deep. Compost and fertilizer are incorporated at the bottom of the trench.

Turmeric does not require hilling and can be planted at a four-inch depth.

Both crops are planted in single rows that are 42 inches apart , if possible. Ample space is given for hilling the ginger. In-row spacing of seed pieces is five to six inches.

Ginger and turmeric are heavy feeders and are fertilized at rates similar to those used for tomatoes. Compost is applied at 15 to 20 tons per acre. Fertilizer is added at planting in the trench. Total plant nitrogen requirements are 150 pounds per acre, but only two-thirds of the nitrogen requirements are applied at planting in the trench. The remaining fertilizer is split into two sidedressed applications to coincide with hilling.

High tunnels are recommended for growing both turmeric and ginger, as these crops benefit from added heat, humidity, and extended length of the growing season to reach maximum potential yield.

Seed piece ready to plant.

Turmeric shoots in the greenhouse, ready to plant.

The solar greenhouse is filled with turmeric and ginger. Each bed has two lines of drip tape.

CROP HANDBOOK: GINGER AND TURMERIC

Family: *Zingiberaceae*

Cultural Practices

Ginger is hilled twice during the growing season. The first hilling happens once the base of the shoot turns from white to pink. The second hilling occurs four to six weeks following. At each hilling, four to six inches of growing media is brought on top of the plants. An additional 25 pounds of nitrogen per acre is also applied at each hilling event, for a total of 50 pounds of nitrogen per acre. Turmeric, while not hilled, also receives the additional fertilizer at the same time as ginger. For turmeric, the added fertilizer is incorporated in the top two inches of soil with a scuffle hoe.

Ginger and turmeric need two lines of drip tape on top of each bed, placed on either side of the row. These lines are removed for ease during hilling and then replaced. Consistent watering is critical, but soil is allowed to mostly dry between irrigation events. Watering every other day may be necessary when grown in high tunnels and the solar greenhouse.

When cultivating weeds in ginger, hoes and hand tools should be used shallowly to avoid damage to the shoots that may be pushing up from underneath.

Ginger and turmeric have few pest problems. Possible insect pests may include wireworms, cutworms, and lepidopterans, but these have not occurred at UK-CSA.

Maintenance with weeding, hilling, and irrigating via drip lines.

Digging below soil surface reveals the pink zone, which indicates it is time to hill.

Washing baby ginger reveals the pink zone vividly.

CROP HANDBOOK: GINGER AND TURMERIC

Family: *Zingiberaceae*

Harvest

Harvest of baby ginger begins four to six months after planting, usually in early October. Baby ginger will have a more fragile epidermis. Plants are gently lifted with digging forks. Six to eight inches of greens are left on the plant if desired, or greens are clipped to within an inch or two above the rhizome, in the pink zone.

Turmeric takes slightly longer to bulk up. Harvest usually begins in late October and may continue into December.

Leaves on plants will begin to brown as the season progresses and the temperatures dip below 40°F. As long as one inch of green shoot is above the rhizome, plants can remain in the ground. Once a killing freeze occurs, plants will quickly brown and wilt. At this point, the crop is harvested quickly.

The lifted turmeric plants have greens clipped.

These turmeric plants are browning from the cold and will be harvested quickly.

CROP HANDBOOK: GINGER AND TURMERIC

Family: *Zingiberaceae*

Yield

Ginger has a large expansion ratio. For every one pound of seed planted, an average of 5.6 to 6.5 pounds of baby ginger is harvested. Some growers can receive 10 or 12 pounds back for every pound planted.

Turmeric is not as vigorous and will take longer to put on weight.

Ginger and turmeric are both specialty CSA crops. CSA shares will occasionally receive dried ginger or turmeric powder in their first shares of the year, and fresh ginger root in their last shares, when ready. Sometimes ginger and turmeric are only made available for purchase around Thanksgiving. CSA members usually receive 1.0 to 1.5 ounces of ginger or turmeric powder at a time, bagged in 4-mil, four-inch-by-four-inch, reclosable-zipper poly bags, or 0.25 to 0.5 pounds of fresh ginger or fresh turmeric roots, either bagged in plastic or held in a quart-sized, green, molded pulp fiber produce basket.

Expansion ratio of ginger can be as much as 1:12.

Family: *Zingiberaceae*

Post-harvest Handling

The ginger and turmeric roots are washed by spraying them off with a hose, because dirt gets into the many crevices. Soaking the roots in the bubbling dunk tank inside a harvest bin also aids in getting the dirt out of crevices, but it is followed by a quick hose spray as a final washing step.

Turmeric is soaked in the dunk tank bubbler and sprayed off to remove soil.

After washing, large turmeric roots will be divided and have roots trimmed.

Family: *Zingiberaceae*

A last trimming with a serrated knife or hand pruners removes any roots and trims leaf stubs, if needed.

Fresh baby ginger after washing and trimming.

Baby ginger and turmeric will be weighed into 0.25- to 0.5-pound increments and packed in plastic bags or produce baskets.

CROP HANDBOOK: GINGER AND TURMERIC

Family: *Zingiberaceae*

Fresh baby turmeric, weighed into a produce basket.

Storage

Turmeric and ginger are kept at 32°F until delivery. Baby ginger and turmeric will only last two to three days in the cooler at peak freshness.

Preservation

Ginger and turmeric can be preserved by freezing in plastic bags. In the freezer, the roots can last for many months. Portions of the ginger or turmeric roots are grated off for use, and any unused portion is returned to the freezer. Thawing the roots results in a loss of texture and is not recommended once frozen.

Both ginger and turmeric can be dehydrated and ground for powder. When dehydrating turmeric, the roots must be peeled and boiled for one hour prior to dehydration to soften the root. Roots of both are sliced thinly before loading into the dehydrator, and they are ground into powder once dehydration is complete.

Ground ginger powder and ground turmeric powder are distributed in poly reclosable bags.

CROP HANDBOOK: GREEN ONIONS

Family: *Allium*

Varieties

The preferred green onion variety grown is Parade. For late plantings or overwintering, Evergreen Hardy White bunching onions are grown.

Plants mature in 60 to 65 days from transplant.

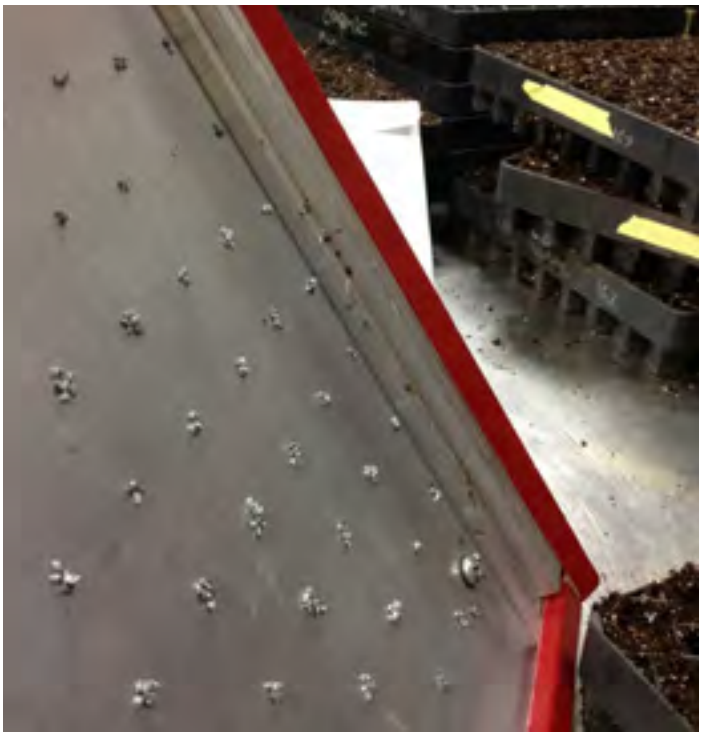
Greenhouse Production

Green onions are started in 128-cell Winstrip trays in the greenhouse in February or March for spring harvest, in May for late summer harvest, and in August for overwintering. Unlike bulb onions, green onions are vacuum seeded, with five to eight seeds per cell. The seeds will clump on the vacuum seeder, which approximates the multiple seeds per cell. Alternatively, the vacuum seeder can drop seeds over a single tray several times in succession to get multiple seeds in each cell.

Green onions do not develop strong root systems readily and are not potted up. Green onions will grow for 10 weeks in their greenhouse trays. They will benefit from greenhouse fertigation weekly after eight weeks of growth.

Field Preparations

Green bunching onions are grown in the bare-ground production system.



Multiple green onion seeds on the vacuum seeder will give clumps of onion plants in each cell.

Seeds still attached to green onion tips in the greenhouse after germination.

CROP HANDBOOK: GREEN ONIONS

Family: *Allium*

Transplanting

Green onions are transplanted on two rows using the Mechanical Transplanter planter and spaced nine inches apart in-row. They are hand-planted on three rows when overwintering in the solar greenhouse or high tunnel.

Earliest planting date in Kentucky is March 25, and latest is July 25 for fall green onions. For overwintering, green onions are planted by November 1.

Green onions require 100 pounds of nitrogen per acre. Fertilizer is applied at planting.

Cultural Practices

Plants are basket weeded and then finger weeded weekly until they are too tall for the tractors to ride over them.

Thrips will sometimes cause feeding damage to the greens themselves, which appears as stippling. Plants are monitored for thrips, but onions can still be given out in CSA shares with minor pest damage.

Harvest

Green onions can be harvested small as scallions, but at UK-CSA they are harvested when fully grown. Fully grown green onions take about two months after transplanting to be ready for harvest, however they are taken before any yellowing of their leaf tips occurs. When the soil is hard, green onions are harvested with the aid of a digging fork to loosen the soil prior to pulling the bunches out of the ground. When the ground is moist, bunches may be readily pulled out by hand without the aid of a digging fork. Workers take care to not snap off the white base of the onion that is held below the soil surface.

Each plant is a clump of five to eight onions. Clumps are separated into individual onions. Yellowed and browned leaves are peeled off in the field. Soil clods are dislodged from the roots. While roots can be trimmed with pruners if time permits, trimming roots is not necessary. Piles of cleaned onions are then assembled into bunches of five to six for larger onions or six to eight for smaller onions. Each bunch is held

Two-row system in the open field.

Three rows of staggered green onions planted in the solar greenhouse.

Family: *Allium*

together with a rubber band. Bands are twisted around the necks of the plants, where the white onions begin to turn to green. By laying a harvest tote on its side, the green onions can be packed neatly without bending the tips.

Green onions harvested with the aid of a digging fork.

Cleaned onions are ready for banding.

Onions are cleaned into piles for bunching.

Bunched onions are stacked into bins on their sides for easier packing. Pruners can be used to trim roots in the field.

CROP HANDBOOK: GREEN ONIONS

Family: *Allium*

Bunched green onions with proper rubber band placement.

Green onions that are tall are quickly trimmed with shears in the packing shed.

The outdoor bunched washing station can be used to wash green onions.

Yield

Green onions yield 0.9 to 1.1 bunches per row foot.

In CSA shares, green onions are only given out once in early summer and once in the late summer or early fall.

Post-harvest Handling

Bunches of green onions can either be washed at the bunched washing station or in the rinse conveyor. Since most of the field soil is removed at the harvest stage when peeling back layers, the washing is for hydrocooling and dislodging any remaining soil held in the roots.

If the greens are excessively tall, they may not fit into any of the bins. Tops can be trimmed off with shears to make them easier to pack. Any leaf tips that have begun to yellow can be trimmed or pinched off.

Bunches are packed either into yellow bins, light-green bins, dark-green bins, or green horticulture bins. Green onions are lightweight, and bins can hold many bunches without becoming too heavy.

Storage

Green onions are stored at 32°F. They hold for five to 10 days in the cooler.

Cleaned bunches ready for packing.

CROP HANDBOOK: HERBS, ANNUAL

Family: *Apiaceae* (Cilantro, Dill), *Lamiaceae* (Basil)

Varieties

Cilantro varieties grown are Calypso and Caribe. Dill variety grown is Bouquet.

Basil varieties grown include Prospera and Aroma 2.

Cilantro and dill annual herbs mature in 45 to 50 days from direct seed.

Basil matures in 68 to 74 days from direct seed, or 54 to 64 days from transplant.

Greenhouse Production

While all three herbs can be grown as transplants, cilantro and dill are equally suited for direct seeding and are usually direct seeded in order to have more dense plantings.

Basil is grown in 128-cell Winstrip trays. Plants need six weeks of growth before planting. Minimum air temperatures must be 45°F to begin hardening basil off outside.

Field Preparations

Annual herbs are grown in bare ground.

Direct Seeding

Cilantro and dill are direct seeded using the MaterMacc VegiMacc seeder. Cilantro uses plate 96, 2.5 and is spaced at 1.2 inches, using sprockets 17-18. Dill uses plate 180, 0.8 and is spaced at 0.8 inches, using sprockets 22-17.

Cilantro and dill require 100 pounds of nitrogen per acre, which is all applied at seeding.

Transplanting

Basil is transplanted at nine-inch in-row spacing.

Basil requires 100 pounds of nitrogen per acre, which is all applied at planting.

Cultural Practices

Dill and cilantro will require hand-weeding after planting as they take longer to germinate and weeds will get a head start.

While swallowtail butterfly caterpillars will frequently be spotted among the dill, they seldom cause significant damage and can be tolerated.

When cilantro begins to bolt, it can no longer be harvested. On the other hand, flowers on basil and dill are fine to harvest. Basil flowers can also be pinched off to promote continued leaf production.

Basil is susceptible to damage from Japanese beetles. Right after planting, hoops and coverings are placed over the crops to protect them from pest damage. The earliest planting of basil benefits from added warmth and is row covered. The

Cilantro and dill are hand-weeded after germination.

Swallowtail butterfly caterpillar munching on dill.

Family: *Apiaceae* (Cilantro, Dill), *Lamiaceae* (Basil)

Basil is protected from spring cold and Japanese beetles by row cover.

Cilantro is cut at ground level, above the growth point.

second succession planting of basil is covered with ProtekNet netting as heat benefits are no longer needed.

Harvest

Cilantro and dill can be harvested as soon as it is five to six inches tall. Basil is first harvested after it grows to a larger plant size of at least 12 inches.

Using a small harvest knife, cut cilantro above the growth point close to soil level. Gather several plants into one's hand, or approximately two row feet of plants. Use a small rubber band to band the stems together. Use the harvest knife to trim the cut ends even. Dill is similarly cut and managed, however dill also produces multiple growth points and spreads out. More selective cuts are made throughout the plant as it grows taller to encourage continued growth. Dill flowers are harvested and included in bunches with the leaves.

When basil is cut, pruners or small knives are used. Plants are cut by one-third to one-half, straight across. Bunches are made from one to two plants, stems held together with a thick rubber band.

Cilantro and dill will be ready for a second harvest in two to three weeks, while basil may need three to four weeks of regrowth before harvesting again.

Herbs are harvested on the same day as distribution to maintain their quality.

Dill as it grows is more selectively harvested for both leaves and flowers.

CROP HANDBOOK: HERBS, ANNUAL

Family: *Apiaceae* (Cilantro, Dill), *Lamiaceae* (Basil)

Basil is harvested by cutting the plant back by one-third to one-half.

Dill fronds and flowers are bunched for CSA shares.

The diameter of a cilantro bunch is around one and a half to two inches across.

CROP HANDBOOK: HERBS, ANNUAL

Family: *Apiaceae* (Cilantro, Dill), *Lamiaceae* (Basil)

Yield

Basil yields 0.8 bunches per row foot.

Cilantro and dill yield 0.45 bunches per row foot.

Herbs are a specialty item in CSA shares. Each herb will be in CSA shares at least two times during the season; sometimes herb variety is a choice for members. Each member receives one herb bunch per distribution. Basil is paired with tomatoes for shares, and dill is paired with cucumbers, when timing of crop harvests accommodates these pairings.

Post-harvest Handling

Herbs are not washed. They are counted and packed immediately into yellow bins.

Storage

Basil is kept at ambient temperature until distribution, while cilantro and dill are held in cold storage at 32°F.

Example of a good cilantro bunch size for CSA shares.

CROP HANDBOOK: KOHLRABI

Family: *Brassicaceae*

Varieties

There are two types of kohlrabi: smaller headed types and larger storage varieties. Smaller kohlrabies grown include Winner and Kolibri. Kossak is a larger storage type.

Winner and Kolibri mature in 45 days, while Kossak is longer-growing and matures in 80 days from direct seed. From transplant, smaller kohlrabies may be ready in 30 to 40 days.

Greenhouse Production

Kohlrabi is seeded into 128-cell Winstrip trays. They are transplanted at four weeks of age.

Field Preparations

Kohlrabies are transplanted into the bare-ground production system.

Kohlrabi requires 50 pounds of nitrogen per acre, and all fertilizer is applied at time of transplanting.

Transplanting

Both types of kohlrabi are planted using the Mechanical Transplanter planter. Faster maturing varieties of kohlrabi are planted at nine-inch in-row spacing. These kohlrabies can also be planted at six-inch spacing if hand-planted, but nine inches is the closest in-row spacing allowed on the equipment. Storage varieties grow larger and should be spaced 12 inches apart in-row.

Cultural Practices

Hot-water seed treatment is practiced to reduce *Alternaria* diseases. Kohlrabi, like other brassicas, is susceptible to insect pests, most notably cutworm, flea beetle, and harlequin bug. Since they are fast growing, kohlrabi is not usually covered. If worms are an issue, Bt is sprayed.

Plants are basket weeded and then finger weeded weekly until bulbing and expansion increases.

Transplanting with the Mechanical Transplanter planter.

Small kohlrabi just beginning to bulb. One final finger weeding cultivation pass can be done at this stage.

CROP HANDBOOK: KOHLRABI

Family: *Brassicaceae*

Mature kohlrabies in the field will have most of the leaves clipped off at harvest.

Harvest

Smaller kohlrabies are harvested when the bulbs are evenly filled out at three inches in diameter. Kossak storage type is harvested when the crop diameter is eight to 10 inches.

Kohlrabi has a very thick stem. This stem is best clipped with pruners. Plants are angled away from the ground, and the roots are clipped below the kohlrabi bulb. Alternatively, plants can first be pulled entirely out of the ground and stacked in piles or rows for root clipping. Leaves at the top center of the bulb are left attached, while the larger outer leaves are trimmed flush to the bulb. This is purely decorative. If the kohlrabi is going to be stored, all leaves are removed. Leaves are not pulled off by hand, as tearing the outer skin is likely, which compromises storage life. Pruners or a small knife is used to remove leaves close to the bulb surface.

The weight of kohlrabi will quickly add up in a harvest bin. Harvest bins are only filled two-thirds full, or they will require two workers to carry them to the harvest wagon.

Kohlrabies are hand-pulled and laid on the bed top for root and leaf trimming.

CROP HANDBOOK: KOHLRABI

Family: *Brassicaceae*

Yield

Kohlrabi yields 1.3 heads per row foot for smaller varieties.

Kohlrabi is a specialty crops that is only given out one to two times a year. Storage varieties are not grown every year, as customers prefer smaller kohlrabies. Members receive one storage kohlrabi or two regular kohlrabies.

Post-harvest Handling

Kohlrabi with leaves attached is washed on the bunched washing station or sent through the rinse conveyor. Kohlrabi bulbs with all leaves cut off are washed on the brush washer. Count kohlrabies into light-green bins. About 40 to 50 bulbs can be held in a bin at a time. For storage kohlrabi, bulbs can be kept in a macro bin until distribution.

If greens are left attached, kohlrabi can be washed on the bunched washing station pictured, or the rinse conveyor.

If greens are clipped, bulbs are sent through the brush washer.

CROP HANDBOOK: KOHLRABI

Family: *Brassicaceae*

Bulb kohlrabi with greens removed can store for several weeks.

Storage

Brassicas can all be stored at 32°F.

Bins should be covered with plastic to trap moisture. Most kohlrabi stores for two to three months, and Kossak may store for even longer.

Storage varieties can be kept in a macro bin or smaller bins for even longer.

CROP HANDBOOK: LEAFY GREENS (DIRECT SEEDED)

Family: *Brassicaceae* (Arugula, Kale, Mustard, Mizuna, Tatsoi, Asian Greens); *Asteraceae* (Lettuce); *Amaranthaceae* (Spinach)

Varieties

Direct-seeded greens may include any of the following: lettuce and salad mixes (Allstar Gourmet, Wildfire); arugula (Astro); baby kale (Ironman Kale Mix); mustards (Miz America); mizuna (Mizuna); tatsoi (Tatsoi, Red Cloud); Asian greens (Tokyo Bekana); and spinach (Butterflay, Corvair, Responder, Space).

Arugula, lettuce, and spinach are harvestable in 21 to 28 days. Most Asian greens reach full maturity after 40 to 45 days, all from direct seed.

Field Preparations

These leafy greens are direct seeded on bare ground, in two rows per bed top in the field production system and four to six rows per bed top in the biointensive plots and tunnels. Beds with four rows have two lines of drip tape laid on top of the bed, staggered to supply water to two rows each. With five to six rows, three lines of drip tape are used. Drip tape is secured with sod staples every 15 to 20 feet to keep the drip lines in place.

Two-row field of lettuce mix.

Six rows of spinach.

Four types of braising greens, planted one type per row in the tunnels.

CROP HANDBOOK: LEAFY GREENS (DIRECT SEEDED)

Family: *Brassicaceae* (Arugula, Kale, Mustard, Mizuna, Tatsoi, Asian Greens); *Asteraceae* (Lettuce); *Amaranthaceae* (Spinach)

Direct Seeding

Greens are seeded using the MaterMacc VegiMacc vacuum seeder. Greens are not singulated when seeded. Arugula, braising greens, and lettuce mix use seed plate 180, 0.8 with 0.6-inch spacing on sprockets 22-17. Spinach seeds vary in diameter, but they are much larger than lettuce and arugula. Spinach uses seed plate 144, 2.5 and is seeded at 1.2-inch spacing on sprockets 17-20.

In tunnels and biointensive seedings, the single Jang JP-1 push seeder or the Jang JP-6 six-row push seeder are used, with one or up to six hoppers respectively. Jang seed roller selection depends on crop variety and desired density. A full list of Jang settings by crop variety can be found at the grower's library of Johnny's Selected Seeds . The commonly used Jang seed rollers by crop are:

- YYJ-24 for arugula, mizuna, and tatsoi, at 0.5-inch spacing and four to six rows per bed
- MJ-24 for spinach, at 0.5-inch spacing and four rows per bed
- F-24 for lettuce mix, at 0.5-inch spacing (or MJ-24 for denser seeding) at four to six rows per bed

Four varieties of braising greens are grown in one bed. These greens usually include mizuna, tatsoi, and two others, like red tatsoi, arugula, Tokyo Bekana variety, or Miz America variety. In the field, crops are blocked in quarter-bed sections for ease in management. However, in biointensive areas, crops are seeded side by side, with each variety in its own row. This eliminates the need to switch out seed in the hoppers of the Jang seeder.

Greens need 125 pounds of nitrogen per acre, which is all applied prior to seeding in biointensive areas or at seeding in the field.

Cultural Practices

Greens in the brassica family (arugula, mustard, mizuna, tatsoi, and Asian greens) are susceptible to flea beetle damage and are netted at the time of seeding. Hoops are placed over beds to keep 47-gram ProtekNet netting from touching

Single-row Jang Precision Seeder can make several passes for multiple rows.

The ganged Jang JP-6 push seeder unit is heavier to maneuver, but the number of rows and spacing is customizable.

Family: *Brassicaceae* (Arugula, Kale, Mustard, Mizuna, Tatsoi, Asian Greens); *Asteraceae* (Lettuce); *Amaranthaceae* (Spinach)

greens, which would allow insects to feed through the net on the leaves.

Crops are monitored for aphids as well, particularly on lettuce when soil nitrogen is high. Crops grown in high tunnels are more susceptible to aphid outbreaks as temperatures warm. Ladybugs can be ordered and released in tunnels at dusk by misting plants and shaking ladybugs around plant base.

Greens are hand-weeded as needed. In the field with two rows, the basket weeder is used after germination to shallowly cultivate. Finger weeders are aggressive and can rip plants out, so the fingers are adjusted to wider spacing prior to cultivation.

Immediately after first harvest, the basket weeder is used to cultivate the bed tops to help prepare for a clean second harvest. In biointensive plantings, the tine rake is used to cultivate the bed tops after harvest. The rake also does a decent job of pulling out leaves left behind.

Beneficial insects like ladybugs can be released on greens for biocontrol of aphids.

Netting protects arugula from flea beetles and is pulled off prior to harvest.

Basket weeding after a lettuce mix harvest.

CROP HANDBOOK: LEAFY GREENS (DIRECT SEEDED)

Family: *Brassicaceae* (Arugula, Kale, Mustard, Mizuna, Tatsoi, Asian Greens); *Asteraceae* (Lettuce); *Amaranthaceae* (Spinach)

Harvest

All greens are cut with lettuce field knives or serrated knives. Some greens can also be cut using the Quick Cut Greens Harvester. The plants that do the best with the Quick Cut Greens Harvester include smooth spinach, lettuce mix, arugula, and mizuna. Using the Quick Cut Greens Harvester requires at least two to three fully charged batteries for the drills powering the cutter. In addition, two people should pair up to use the Quick Cut Greens Harvester. The harvesting tool can tire the worker holding it. The harvester's partner can relieve them by taking the full load and dumping it into a harvest bin. In addition, the pair can switch jobs to give each a break.

The spinach growth point can be spotted where baby leaves are emerging. Harvest cuts are made above this point.

Proper knife position is critical when harvesting. Hold greens in one hand while cutting with the other.

Harvesting with the Quick Cut Greens Harvester, top, and switching off, bottom.

CROP HANDBOOK: LEAFY GREENS (DIRECT SEEDED)

Family: *Brassicaceae* (Arugula, Kale, Mustard, Mizuna, Tatsoi, Asian Greens); *Asteraceae* (Lettuce); *Amaranthaceae* (Spinach)

Loose greens are harvested past baby crop stage to maximize yield but must be harvested before leaves get too large and bitter tasting. Lettuces should fill out the row and stand five inches tall or more before harvesting. Mizuna may reach seven to eight inches before harvest as one of the fastest-growing greens. Spinach leaf size should be smaller than one's palm. Arugula at three to four inches makes a nice baby leaf, but usually reaches six to seven inches tall prior to harvest.

To harvest efficiently, both hands are used. While one hand holds the knife, the other grabs a large handful of leaves between thumb and fingers. Position preferred cutting implement just above the growth point before cutting evenly parallel to the ground. For successive harvest, the cuts should be made slightly higher than the one previous. Most lettuce mixes in May and June will only yield two harvests before quality declines.

Harvesting braising greens in the field. Squatting in the field saves workers' backs.

A harvester checks size of bunched arugula before banding.

After cutting, the leaves are held in hand loosely to avoid crushing leaf tissues. The bundle is inspected for yellowed leaves, rotten leaves, or weeds. All of these are removed while holding them in hand. Once the handful is clean, leaves are dropped into a clean harvest bin nested into a drag bin. One row is cut at a time on double-row beds, with harvesters starting at either end of the field and working toward the others to meet in the middle. Once a bin is full, having been lightly pushed down from above to fill the bin well, the nested harvest bin is pulled out of the drag bin and brought to the harvest wagon in the drive row. Bins are placed in the shade beneath the wagon. Keeping greens out of direct sunlight and bringing them to the pack shed quickly after harvest are key to high green quality.

A harvest bin holds six to 10 pounds of greens, depending on variety and pack density. For the CSA, members ideally receive a half-pound of greens per distribution. For braising or cooking greens, the ideal quantity is 0.75 pounds, since they will cook down.

Spinach and arugula are also occasionally bunched at harvest rather than harvested loose. Spinach is cut into bunches, having the plant cut below the growth point in the root zone. The bunching method removes the entire plant and removes the chance for second harvest. Several plants are gathered in hand and aligned, and then they are banded with a twist tie or rubber band at the highest possible point on the stem, closest to the leaf base. Arugula can still be cut as loose greens, but greens are gathered in hand and tied with a rubber band around the base. The amount of greens should be about two inches in diameter when held tightly at the stem base.

Yield

Green yield varies by planting location and field conditions, as well as time of year.

Arugula averages 0.21 pounds per row foot. Lettuce mix averages 0.39 pounds per row foot. Spinach averages 0.26 pounds per row foot. Braising greens (mizuna, tatsoi, Asian greens, mustards) average 0.40 pounds per row foot.

All loose greens, particularly lettuce mixes, are a staple crop in the CSA shares. Loose lettuce mixes are alternated with head lettuce for variety. Lettuce mix is in shares four to six times a year, in both early season and late season. Spinach is given out four to six times as well, split between late spring and fall. Arugula is always included at least once in both spring and fall; in spring, arugula bolts quickly, making a second harvest unreliable. Other loose greens, like Asian greens and baby kale, are specialty items and may only be included in shares one to three times a year.

CROP HANDBOOK: LEAFY GREENS (DIRECT SEEDED)

Family: *Brassicaceae* (Arugula, Kale, Mustard, Mizuna, Tatsoi, Asian Greens); *Asteraceae* (Lettuce); *Amaranthaceae* (Spinach)

Greens are washed in the dunk tank with the bubbler.

Post-harvest Handling

Greens are washed in the dunk tank with the bubbler. Approximately four to five full bins can be emptied into the tank at one time for washing and agitation. Workers look for any large weeds or debris to remove by hand. All loose greens are loaded into one of the Electrolux-Dito Electric Vegetable Dryers. These industrial salad spinners have a removable basket to hold greens, which is filled no more than three-quarters full. Each spinner is run for one and a half to two minutes to remove excess water. Spinners are alternated so that a spinner is always working while another is being loaded or unloaded. Spun greens are emptied into clean, dark-green bins, weighed, and taken into the cooler. Any weeds spotted are pulled out as greens are dumped into bins.

Two Electrolux industrial salad spinners work in tandem to remove excess water from leaves.

Spun greens are unloaded into a dark-green bin.

CROP HANDBOOK: LEAFY GREENS (DIRECT SEEDED)

Family: *Brassicaceae* (Arugula, Kale, Mustard, Mizuna, Tatsoi, Asian Greens); *Asteraceae* (Lettuce); *Amaranthaceae* (Spinach)

When bagging, check for and remove weeds.

Once the dunk tank is nearly empty, a mesh skimmer is swept across the water surface to collect final leaves and prepare for the next wash cycle.

Bunched spinach and arugula are washed in the dunk tank with the bubbler and should simply be shaken prior to setting in a dark-green bin.

Dark-green bins hold around 20 pounds of loose greens. Greens are ideally left to drip dry for a few hours or overnight prior to bagging into individual CSA share amounts. Greens are weighed in plastic bags, and any remaining weeds spotted are removed at this stage. Bags are filled to the appropriate weight. The bags can be either twisted to close, releasing a portion of the air prior to the twist, or the tops can be folded over cleanly. Bags are placed in dark-green bins, with the bag openings sitting on top. Bags should not be compressed, as this will damage leaves.

Bins can hold around 15 to 20 bags per bin, split in two layers.

Loose greens are bagged using scales and plastic bags before being packed into dark-green bins.

CROP HANDBOOK: LEAFY GREENS (DIRECT SEEDED)

Family: *Brassicaceae* (Arugula, Kale, Mustard, Mizuna, Tatsoi, Asian Greens); *Asteraceae* (Lettuce); *Amaranthaceae* (Spinach)

Storage

Greens are stored at 32°F. If greens are loose, bins are covered with plastic pallet covers. Greens will last for seven to 14 days. Kale may last longer, up to three weeks.

Bunched arugula and bunched spinach, left and right, are banded with a twist tie or rubber band.

Loose salad greens, left, and loose spinach, right, are packed into plastic bags, and bags are layered into bins, right. Greens are packed with care so as not to crush leaves.

CROP HANDBOOK: LEEKS

Family: *Allium*

Varieties

Leek varieties grown are King Richard, and Bandit for overwintering. Leeks can withstand temperatures down to 20°F, or possibly lower when choosing an overwintering variety; Bandit is more likely to withstand colder temperatures in winter than King Richard.

King Richard is an earlier leek, ready in 75 days from transplant. Bandit takes 120 days.

Greenhouse Production

Leeks are seeded two to three seeds per cell in 128-cell Winstrip trays for germination. After five to six weeks, leeks are potted up to 72-cell Winstrip trays, with one plant per cell. Leeks spend 12 weeks in their greenhouse trays and will benefit from weekly fertigation the last two to three weeks before planting. Seeds are started in the middle of February for an early May planting.

Leeks have distinct V-shaped leaves.

Transplanting

Leeks can be planted three different ways. The key for good leeks is to grow a long, white shank on the plant. The white part of the plant is the part that is most desirable for cooking and eating. These methods of planting will all accomplish this goal, with varying tradeoffs.

1. Transplant into bare ground with Mechanical Transplanter planter or hand-planting, followed by regular hilling. This method is simplest, however there is considerable hand labor with chop hoes to keep weeds controlled and hills maintained. There is also an upper limit of what amount of hilling you can do on top of the plants.
2. Augur six-inch holes in the soil, then hand-drop plants into each hole, scuffing soil into the hole only partway with one's shoe. As plants are cultivated over the course of the season, and more soil will backfill as the plant grows. This is a beautifully efficient way to get long, straight, white shanks. However, there is considerable labor on the front end to accomplish the planting. In addition, it is easy to burn through drill batteries when using the augur.

Planting leeks by auguring holes.

CROP HANDBOOK: LEEKS

Family: *Allium*

Plants are dropped in the hole.

Leek cultivations gradually fill in the soil on top.

3. Plant and cultivate leeks as you would a potato. In the UK-CSA system, two rows of trenches are dug 30 inches apart. Leeks are hand-dropped into the trenches, and all should be angled to lay on the same side of the trench. The potato tool bar with hiller discs is used to bury the bottom part of the leek. Leeks may sit somewhat sideways, which produces some curved shanks. However, leeks can be cultivated by tractor with the Lilliston Rolling Cultivators and hilled in this manner as well.

Planting leeks by dropping plants in trenches and then hilling with Lilliston Rolling Cultivators.

CROP HANDBOOK: LEEKS

Family: *Allium*

Leeks lay on top of the soil after being dug.

The third method has become the standard leek-planting system.

In-row spacing for leeks is five to six inches.

Leeks require 150 pounds of nitrogen per acre. Two-thirds of the fertilizer requirement is sidedressed pre-planting with the Lilliston Rolling Cultivators.. The remaining fertility is provided by fertigation after eight to 10 weeks of growth.

Cultural Practices

Leeks are hilled two times with the Lilliston Rolling Cultivators. Workers walk the field to scuffle or chop hoe any weeds not taken out by the cultivator.

Harvest

The leek's readiness is determined by the overall diameter of the shank, which should be around 1.5 inches. The lowest leaves may have begun to yellow. Leeks are harvested by hand with a digging fork. The greens are very long and can be chopped off straight at the top or at an angle on either side to create a fan shape at the top. Roots are trimmed to a quarter-inch or less, using pruning shears or a serrated knife. Leek roots are inspected for entrance holes caused by root maggots, and any that have been affected are culled. Browning of tissues and a sour rot smell is frequently present when root maggots have burrowed into a leek.

A pair of workers trim leek tops with hedge shears into a fan shape, as seen below.

Leeks after trimming tops into fan shape.

CROP HANDBOOK: LEEKS

Family: *Allium*

Washing leeks at an outdoor washing station. The main focus is to loosen soil caked into roots. Roots are trimmed in advance for easier washing.

Post-harvest Handling

Leeks are washed using the bunched washing station or sent through the rinse conveyor. Higher pressure sprays may be needed to dislodge soil from the tight roots. Leeks are counted and stacked lengthwise, facing in the same direction, into light-green or dark-green bins. Total number of leeks per bin is recorded on labeling tape that is placed on the end of the bin, and bins are stacked in the cooler.

Yield

Leeks suffer from root maggots that burrow into the base of the white shank and create an area for rot. Some years have resulted in up to a 33-percent loss. Average yields have ranged from 0.82 leeks per row foot to two leeks per row foot.

For CSA shares, leeks are given out one or two times a year. Each share receives three to four leeks per bunch. Leeks can be bunched with a rubber band or kept loose as individual stalks. Leeks are frequently paired with an early potato for distribution in late July.

Storage

Leeks are kept under refrigeration at 32°F. Bins are covered with plastic pallet covers at the end of the day.

Leeks are given out in the CSA shares in bunches of three to four banded together, or they are loose and selected individually.

CROP HANDBOOK: LETTUCE, HEADS

Family: *Asteraceae*

Varieties

There are several different types of lettuce heads that are included in CSA shares ever year. Butterhead lettuces, grown only in spring, include Mirlo and Nancy. Leaf lettuces include Green Star and Ruby Sky. Batavian lettuce heads grown are Lovelock and Muir. Romaine lettuce heads grown are Coastal Star, Jericho, and Winter Density in the off season. Oakleaf lettuce heads grown are Panisse.

In addition, Salanova lettuces are grown as heads but are harvested as looseleaf lettuces. The Foundation Collection and Premier Collection are grown together.

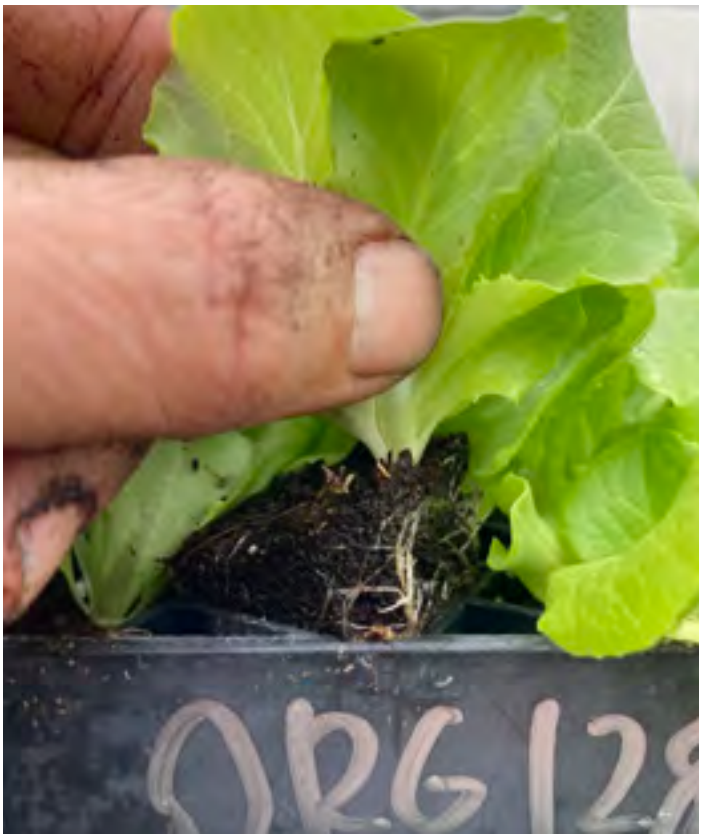
Head lettuces mature in 50 to 58 days from transplant for full-size heads.

Greenhouse Production

Lettuce seedlings are started in 128-cell Winstrip trays. They are four to five weeks old at time of transplant.

Field Preparations

Head lettuces are grown in the bare-ground production system. They can also be grown biointensively on bare ground or in woven landscape fabric with holes burned in it, with three to four rows per bed.



Lettuce plug pulls readily from tray and is ready to be planted.

Transplanting

Earliest head lettuce planting date is March 25. The latest planting date is August 1. Cold-hardy varieties like Coastal Star and Winter Density can be planted through the middle or end of September.

Lettuces are transplanted with the Mechanical Transplanter planter, or they are hand-planted in biontensive applications. Heads are spaced 12 inches apart in-row. Salanova types are grown six to eight inches apart in-row, with four rows per bed in the biointensive system.

Head lettuces require 125 pounds of nitrogen per acre. All fertilizer required will be applied at planting.

Four rows of Salanova lettuce, planted in a high tunnel.

Three rows of romaine lettuce, planted on black woven landscape fabric.

CROP HANDBOOK: LETTUCE, HEADS

Family: *Asteraceae*

A two-row field of lettuce, with leaf lettuce on left and butterhead on right.

Cultural Practices

Primary pests of lettuce include aphids, grasshoppers, and slugs, particularly in tunnels. Lettuces are cultivated using the finger weeder until the formation of heads, which can be damaged by the cultivator.

Lettuce is prone to bolting as it matures into the heat of summer. Bolting will cause lettuces to look like Christmas trees if allowed to grow. The middle part of the lettuce head begins to elongate and separate from the outer layers of leaves. This also results in lettuce that tastes bitter. To prevent bolting, keeping lettuce cool is critical. Success with late plantings of head lettuce relies on selecting the best types that are heat- and bolt-tolerant; Lovelock is the most reliable variety in heat. In addition, heads can be kept cool through natural shading from a buffer strip of cover crop, like buckwheat, adjacent to the lettuce bed. The cover crop is seeded a few weeks prior to the lettuce being transplanted to get it established and give it a head start on growth.

Harvest

Lettuce head harvest is based on head size as well as balancing the CSA shares. Doubling up lettuce in a given week is avoided. Lettuce heads should be full but without any evidence of bolting. The center of the heads can be felt for a hard stem that begins to form at the initiation of bolting. If the lettuce is not bolting, no hard stem in the center of the head will be felt. Some romaine lettuces will also have their tips curl inward to form an interior head, known as the romaine "heart," but this does not always develop in every variety. Butterhead types form a rounded center head. Batavian, oakleaf, and leaf lettuces do not form rounded or wrapped centers. These heads stay loose and open in the interior.

Buckwheat planted on the east side of this plot shaded lettuce out and kept heads from bolting prematurely.

A very hot fall resulted in all the romaine lettuces becoming bolted "Christmas trees."

CROP HANDBOOK: LETTUCE, HEADS

Family: *Asteraceae*

Proper lettuce head harvest relies on knife placement.

Lettuce can be harvested on the day of distribution or a day in advance. Lettuce is always harvested at the coolest part of the day. It may be harvested when wet as well; any moisture will help to keep the lettuce fresh. Harvesters use one hand to hold back the leaves and find the first outer layer of leaves that is not yellow, brown, or damaged. Harvesters use the other hand to position a lettuce field knife at the head's base, cutting just above any yellow leaves. Careful cutting leaves damaged leaves, usually on the outermost layer, in the field and eliminates the time that would be spent pulling damaged leaves off by hand. The cut is made through the lettuce stem, parallel to the ground. The cut should be low enough that the head stays intact as one piece; if the leaves of the head begin to fall apart, the cut was made too high.

The cut end will exude a milky-looking fluid that is made of latex, which is naturally occurring. This latex exudate can smear on lettuce leaves and be mistaken for bird droppings. In order to keep the lettuce leaves clean from any latex, pack all heads upside down with the cut ends facing up. Do not lay head lettuce on top of a cut end.

Depending on head size, eight to 14 heads will fit inside a harvest bin.

Yield

Romaine and butterhead lettuces are the lowest yielding, at only 0.5 to 0.7 heads per row foot. Other lettuce varieties have an average yield of 0.75 heads per row foot.

Lettuce is a staple crop in the CSA shares. Members receive head lettuces three to four times in spring and three to four times in fall. Lettuce heads are alternated with lettuce salad mixes. CSA members will easily get overwhelmed by too much lettuce, therefore only one head of lettuce per week is sufficient for the share amount. If heads have to be harvested small, two heads can be banded together as an equivalent amount.

Cut end shown here has a milky exudate.

Above and below, proper packing of lettuce heads in bins.

CROP HANDBOOK: LETTUCE, HEADS

Family: *Asteraceae*

Post-harvest Handling

Lettuce is washed in the dunk tank with the bubbler. The cut ends with the latex fluid should be rubbed well prior to pulling out of the tank. All heads are shaken firmly upside down to drain water out of the interior of the head. Lettuce heads are packed into dark-green bins with the tips facing down. The heads will continue to drip-dry when situated with the tops facing down. Once the cut ends are washed, lettuce heads can be stacked in two layers.

Damaged leaves on the outer layers can be removed; however, many layers should not be removed or the head will lose its size and structure.

Lettuce heads are tabulated by counts per bin. A standard number of heads are packed in the bins for reliable counts that can be double-checked.

Storage

Lettuce is stored in the cooler at 32°F, and plastic pallet covers are placed over the bins for moisture retention.

Some head lettuces, like romaine, will hold in the cooler for 21 days or more. Most head lettuces are best consumed within seven to 14 days.

Panisse oakleaf lettuce head.

Coastal Star romaine lettuce head. The head does not always curl inward at the center.

Butterhead lettuce head.

Lovelock Batavian lettuce head. This head was harvested in the third week of June, with no bolting. Note feet for size reference.

CROP HANDBOOK: PEPPERS

Family: *Solanaceae*

Examples of red bell pepper, left, and yellow bull's horn sweet pepper, right.

Varieties

Green and red bell peppers grown include Aristotle, Labelle , and Socrates.

Orange and yellow bell peppers grown include Milena (tunnels only), Abay, and Golden California Wonder.

Sweet peppers grown include: Carmen and Escamillo. Both are Italian Corno Di Toro, or "bull's horn " types.

Specialty peppers grown change annually but have included the following: Mellow Star (shishito); Boris or Goddess (banana); Jedi or Jalafuego (jalapeno); Red Ember or Red Flame (cayenne); Bangkok (Thai chili); Baron, Tiburon, or Bastan (poblano); Lemon Drop (Peruvian); Helios (habanero); Numex Suave Orange (mild habanero type); Hot Rod (serrano); Hungarian hot wax; Capperino (cherry); and Padron Spanish heirloom.

Specialty peppers are included in the you-pick field and identified for CSA members.

CROP HANDBOOK: PEPPERS

Family: *Solanaceae*

Peppers are grown on black plastic mulch with teff living mulch.

Greenhouse Production

Peppers start in 162-cell Winstrip trays, with two or three seeds per cell. They are placed on a heat mat at 80°F to 85°F until germination and then removed from the heat mat.

After 10 to 21 days, or once seedlings develop true leaves, peppers are potted up to 50-cell Winstrip trays.

Transplants are ready after eight weeks.

Field Preparations

Peppers are grown on black plastic mulch with teff living mulch in between the beds.

Peppers require 150 pounds of nitrogen per acre. Two-thirds of the required fertilizer is applied at time of plastic laying, and the remaining third of the fertilizer requirement is fertigated after eight to 10 weeks of growth.

Transplanting

Peppers are transplanted in the field using the water wheel transplanter, in two rows per bed at 15-inch in-row spacing.

Peppers are transplanted in high tunnels by hand on black woven landscape fabric. Tunnel peppers are planted in two rows per bed at 15-inch in-row spacing. Holes are pre-burned into landscape fabric at this spacing. Six beds with double rows can fit inside one high tunnel. In the caterpillar tunnel, four single rows can fit inside.

Normal planting date in the tunnel is April 10–15. Normal planting date in the field is May 1–10. Latest planting date recommended is July 1.

Peppers are transplanted in the field with the water wheel transplanter. In tunnels, row covers are used in the early season if temperatures drop. Hoops are needed when plants are young.

CROP HANDBOOK: PEPPERS

Family: *Solanaceae*

Tunnel peppers are staked with wooden posts, rebar, or metal T-posts.

Peppers are strung in the Florida weave pattern near the base and strung a second time for additional support.

Cultural Practices

In the field, peppers are not staked. In the tunnel, staking is required due to plant vigor. Stakes are placed between every two plants, and then plants are tied up using the Florida weave. (For more detail, see the Tomato Tying section of the SOP manual.) Plants are secured with the first string about four to six inches off the ground. Second and third strings are added at four-inch intervals as plants grow in order to box plants in and keep them from flopping into the walkways.

The king flower, which is the first flower, is removed from tunnel peppers to aid in establishment and sturdier plant structure to support fruit load.

Common pepper diseases include anthracnose, bacterial spot, and bacterial speck, especially in wet seasons. Copper is a protective fungicide that is applied at regular seven- to 14-day intervals, as needed. Sunscald can also ruin many fruits when leaf coverage is inadequate.

Example of sunscald on pepper.

CROP HANDBOOK: PEPPERS

Family: *Solanaceae*

Harvest

Bell peppers are ready when shoulders are risen above the stem base, and two to four lobes are clearly defined on the bottom of the pepper. First peppers are the largest. Only one to four peppers are usually harvested from a plant at any one time. Largest peppers are harvested first and smaller peppers stay on the plant to fully develop. Any green pepper that is in transition to red is left on the plant until color is 80 to 100 percent developed. All Corno Di Toro peppers, yellow bell peppers, and orange bell peppers are harvested at 80 to 100 percent of full color development; they are not harvested when green.

Each worker harvests from one row of peppers, and all workers harvest in the same direction down the length of the field. Peppers are removed from the plant by hand as long as the stem remains intact. Pruners or small serrated knives are also used to cut pepper stems. Each pepper keeps one to two inches of stem. Harvested peppers are placed in red buckets or brown harvest bins. The bins are carried to the outside field edge for pick up with the harvest wagon.

During harvest, plants are cleaned by clipping off any damaged, diseased, or soft fruits, which are discarded in drive rows for removal from the fields. All culled peppers are removed from tunnels and composted.

Red bull's horn peppers harvested using a small serrated knife and loaded into harvest totes.

Full buckets and bins are carried to the field edge for pick up.

CROP HANDBOOK: PEPPERS

Family: *Solanaceae*

Yield

Green and red bell peppers yield on average 0.35 to 0.5 peppers per row foot. Tunnel peppers, which are exclusively yellow and orange bell peppers, have a yield range of 0.15 to 0.55 peppers per row foot. Sweet peppers have an average yield of 0.38 peppers per row foot. The first flush of peppers is always the greatest.

Peppers are a staple crop and given out in CSA shares 10 to 14 times. Specialty peppers like banana and shishito are distributed two to four times, and hot peppers one to two times. Target quantity per share is two to four bell or sweet peppers, four shishito or banana peppers (or mix and match), and four to six hot peppers (mix and match).

Orange and yellow bell peppers are much higher yielding when grown in a high tunnel.

Family: *Solanaceae*

Post-harvest Handling

Larger peppers are washed using the brush washer. Smaller hot peppers, shishito, and banana peppers are not washed, as they will get caught in the machine. After washing, they are counted into light- or dark-green bins, and each bin is labeled with the final count. When counting and sorting, green bell peppers are counted separately from the red, orange, and yellow bell peppers. Sweet peppers and specialty peppers are also counted separately.

Larger peppers are washed on the brush washer and then sorted.

CROP HANDBOOK: PEPPERS

Family: *Solanaceae*

Any small or damaged fruits, or any with underdeveloped color, are culled. Bin labels are placed on the short side facing outward when bins are stacked.

These peppers do not have 80 to 100 percent developed coloration and should not have been harvested.

CROP HANDBOOK: PEPPERS

Family: *Solanaceae*

Storage

Peppers are stored at 45°F to 55°F. Plastic pallet covers are placed over stacks of bins.

Stakes and T-posts are removed with a T-post remover after the final tunnel pepper harvest.

Mellow Star shishito peppers.

CROP HANDBOOK: POTATOES

Family: *Solanaceae*

Varieties

Potatoes are divided into groups either based on maturity date, by skin and flesh color, or by storage life.

Potatoes that have longer storage and better disease resistance are selected. However, CSA customers love unique potatoes, so potato varieties are diversified beyond the standard buff-skin-with-white-flesh varietals.

Early potatoes (55 to 70 days to maturity) grown with success include Red Gold, Chieftain, and Satina. Red Gold and Chieftain are the primary red-skinned varieties grown.

Mid-season potatoes (70 to 90 days to maturity) include Kennebec, Magic Molly, Nicola, Purple Majesty, Purple Viking, and Salem.

Late-season potatoes (90 to 110 days to maturity) include Elba, German Butterball, and Pontiac.

Magic Molly is the only fingerling grown. It has purple skin and flesh. Purple Viking and Purple Majesty also have specialty coloring.

Chitting

Potatoes benefit from a process of pre-sprouting called chitting to prepare them for planting. Chitting, or green-sprouting, the seed pieces before they go into the soil gives them a head start on the growing season. Whole seed potatoes are set in two to three layers in yellow bins. Bins are stacked in a cool place out of direct sunlight. Bins are labeled with the variety names. The process of chitting takes three to four weeks prior to planting.

Purple Viking potatoes.

Field Preparations

Potatoes are planted on bare ground, in two rows per bed that have been trenched. The trenches help to get the seed pieces planted deeply and allow for hilling on top. The potato tool bar is hooked up to the Kubota 9540 with two Willsie furrowers spaced 30 inches apart. Trenches are dug about four to six inches deep. All trenches are dug in advance of planting to set the bed spacing. The tractor's wheel tracks act as a guide to line up the next beds. A 50-foot-wide field can fit eight potato beds, but they are tight. Wheel tracks must overlap completely. For a seven-bed field, wheel tracks are only overlapped by half to allow a bit more room for hilling and cultivating.

Seed potatoes chitting in bins.

Furrows made in preparation for planting.

CROP HANDBOOK: POTATOES

Family: *Solanaceae*

Planting

Potatoes are cut into pieces prior to planting. The ideal size is two ounces per seed piece. A scale is used to check the cut pieces until workers are adept at cutting the ideal size. Each piece must contain at least one or two potato eyes, which may be sprouting. Cut seed pieces are placed into bins to take to the field. Pieces are handled gently in order to retain the sprouts.

Workers wear apple harvest bags that crisscross across one's back for planting. Each bag is filled with seed pieces. Workers walk along the wheel tracks of each bed and plant one row at a time. Seed pieces are dropped into the trenches and adjusted with one's foot rather than stooping down to fix by hand. This method is efficient and easier to keep both hands free for planting. While the pieces will grow however they land in the trench, it is best to aim to have sprouts topmost. To achieve this, workers are trained to have a very firm throw of each piece into the trench rather than casually dropping it. Workers aim for eight- to 12-inch spacing of seed pieces in-row. This translates to one to two pieces thrown with every step. Workers can even use the length of their own foot as a guide on piece spacing.

Cutting purple Magic Molly potatoes.

All ages can learn the art of the potato-planting throw.

In-row spacing is gauged by foot length.

Family: *Solanaceae*

Once all rows are planted, each bed is covered in succession. The two Willsie furrowers on the potato tool bar are switched out for pairs of hiller discs. The angle and height of the hiller discs are adjusted for optimized covering. The hiller discs lightly cover the pieces as the tractor drives over them. A second pass is sometimes required.

Potatoes are dry-farmed. Drip irrigation lines can be buried into the trenches after the seed pieces are thrown down, but it is challenging to keep them buried when the trenches are filled. A worker will need to follow behind the tractor and make sure the driver stays aligned with the rows, or the irrigation lines may need to be held under tension, so they don't buckle and get out of alignment. This difficulty led to an experiment in dry farming, and no reduction in crop performance was observed.

Planting can be done either early or late. There are advantages and disadvantages to both.

Early-planting challenges include:

- Ability to secure seed potatoes early enough. Some companies will not ship in February or March when risk of freezing is still high.
- Field conditions being dry enough for spading and digging trenches in late March.
- Potential for attack by the Colorado potato beetle (CPB).
- Risk of late freeze.

Early-planting advantages include:

- Getting a head start on potato growth and tuber formation for earlier harvest.
- Avoiding some blight and disease pressures that intensify later in the season by harvesting earlier.

Late-planting challenges include:

- A busier time of year for planting potatoes, coinciding with other plantings.
- More challenging conditions for dry-farming, since May is drier than March and April; irrigation may be required.
- Swifter exposure to disease pressures.

Late-planting advantages include:

- Avoiding the first major generation of Colorado potato beetle (CPB)

After years of doing both, earlier plantings are preferred. The Colorado potato beetle is more easily managed than blights. Conducting proper scouting followed by timely spraying will keep this pest in check. But in some years, blight moves in too quickly and truncates the growing season as plants die back quickly, which is problematic if potatoes were planted late.

The field arrangement of the potatoes is carefully considered. The earliest potatoes are planted on the outside, and the varieties are lined up sequentially based on anticipated harvest date, from early to late.

Potatoes require 150 pounds of nitrogen per acre. Two-thirds of the fertilizer required is applied at planting with the Lilliston Rolling Cultivators, and the final third is applied with the Lilliston Rolling Cultivators at the first hilling cultivation.

Hiller discs cover the seed pieces.

Colorado potato beetle larvae.

Potato plant flowers.

CROP HANDBOOK: POTATOES

Family: *Solanaceae*

Cultural Practices

If a late, hard freeze is expected and potato leaves have already emerged from the soil, best practice is to place a row cover over the field. While this may not be practical, the risk of setting the plants back is substantial. In the past five years of planting early, the farm suffered a hard, late freeze only once. The plants were not covered, and all the greens died back. The plants rebounded and grew post-freeze, but yields were reduced substantially.

Prominent pests to monitor for include CPB; leafhoppers, which cause hopper burn; whiteflies; flea beetles; and aphids. Spinosad, *Beauveria bassiana*, and azadirachtin pesticides can be rotated for pest control, particularly for CPB. The primary disease concern is early blight. Late blight, botrytis, and Septoria leaf spot may also cause issues, depending on the year. Copper and biofungicides can offer protection against blight and Septoria.

Potatoes are cultivated and hilled several times during the growing season. The Lely tine weeder will blind cultivate the plants when they are small. The hills will be knocked back somewhat, but at the early growth stage, it is effective at controlling weeds. As the plants grow larger, the more aggressive Lilliston Rolling Cultivators are used to hill and cultivate simultaneously. Ideally each bed will be hilled twice. A second fertilizer sidedressing will occur at the first hilling event.

Potato plants that underwent a late freeze. At this growth stage, they needed to be row covered.

Potato plants in this field are too large for any additional hilling.

CROP HANDBOOK: POTATOES

Family: *Solanaceae*

Blind cultivation with the Lely tine weeder.

Hilling, cultivating, and sidedressing with the Lilliston Rolling Cultivators.

CROP HANDBOOK: POTATOES

Family: *Solanaceae*

Two rows of potatoes in the middle of the field are starting to dieback, while potatoes on both the left and right are still green and growing.

Harvest

Once the plants begin dieback, a few plants are dug to check for harvest readiness.

Potatoes can stay in the field for several weeks after they are harvestable, but secondary rots are risked.

Plants are mowed with a tractor-mounted flail mower five to 10 days prior to harvest. This will aid in firming the skins of the potatoes.

When ready to harvest, the potato digger is attached to the narrow Kubota M8200 tractor. This digger harvests one row at a time. The digger is run at 540 PTO (power take-off). The machine is set into the field and lowered, but depth is important, as it can dig too much soil if lowered too deeply. The digger may get stuck, or large clods of soil may be drawn onto the conveyor. If there are a lot of weeds, they will also clog the machine. The side discs may need to be lifted with the hydraulics to prevent major clogging. Workers must keep toes and extremities away from the discs that are moving forward. If a worker needs to unclog the machine, the machine must be stopped completely for safety.

Potato harvest using the digger on the narrow Kubota M8200 tractor. Harvest buckets are spaced down the row.

CROP HANDBOOK: POTATOES

Family: *Solanaceae*

Hand harvest is still required, as the potatoes that have been dug will be carried along the digger's conveyor and then set on top of the soil. Therefore, potatoes are hand-picked from the surface and placed into red buckets. Full buckets are kept next to the row, and then the harvest wagon is driven down the row and buckets are loaded onto the wagon. Each bucket gets dumped into an empty macro bin that is set on the wagon. The person dumping the buckets counts each bucket that is placed into the macro bin. Each red bucket will hold 18 pounds of potatoes. A full macro bin will hold 1,000 pounds of potatoes. When growing multiple varieties, the macro bins are labeled with variety names.

The farm crew picks the potatoes from the soil surface into red buckets. The farm crew picks the potatoes from the soil surface into red buckets.

Red-skinned potatoes sit atop the soil after digging.

Full buckets of potatoes are emptied into a macro bin.

CROP HANDBOOK: POTATOES

Family: *Solanaceae*

Yield

Specialty potatoes will have the lowest yield. Magic Molly, for example, is a fingerling and yields about 0.8 pounds per row foot. Red-skinned Chieftain yields around 1.5 pounds per row foot, and the bulkier Kennebec and Elba can yield 1.5 to 2.0 pounds per row foot.

Overall, potatoes are included in CSA shares five to six times. The earliest potato, usually Red Gold, is often paired in CSA shares with the leeks. Each specialty potato is only distributed once. The staple potatoes, including Chieftain and the buff-skinned Kennebec and Elba, are handed out at least two times apiece when yields are good. For each distribution, members receive between three and four pounds of potatoes.

Post-harvest Handling

Potatoes are not washed at UK-CSA.

Storage

Potatoes are kept out of direct sunlight. They are stored in lidded macro bins in a climate-controlled facility. Ideal storage temperatures are cool, around 50°F. Potatoes that are kept over winter for the following year's seed are stored in a colder environment, ideally between 38°F and 40°F.

When potatoes are ready to be handed out, macro bins are brought to the packing shed. Tables are set up around each bin. Teams of three to five will divide the tasks of loading brown paper sacks with potatoes, and another person will weigh and adjust bag contents for the target weight. Bags are folded down and stacked in two layers in dark-green bins. Usually, 15 or 16 bags can fit per bin.

Potatoes are weighed and bagged for CSA shares.

CROP HANDBOOK: RADISH, RUTABAGA, AND TURNIP

Family: *Brassicaceae*

Varieties

Radish varieties grown include Rover, French Breakfast, Nelson, White Icicle, Easter Egg, Red Meat, and Alpine daikon winter radish.

The rutabaga variety grown is Helenor.

Turnips grown include Hakurei salad turnips and Purple Top White Globe.

Radishes mature between 21 and 30 days, except Red Meat and Alpine, which mature in 50 to 55 days. Rutabaga is also a storage crop and matures in 90 days. Salad turnips mature in as few as 38 days. Storage turnips like Purple Top White Globe mature in 50 days. Days to maturity are all calculated from direct seeding.

Hakurei turnips.

Nelson radish.

Red Meat radish, also called watermelon radish, features a bright pink interior.

CROP HANDBOOK: RADISH, RUTABAGA, AND TURNIP

Family: *Brassicaceae*

Helenor rutabaga.

Greenhouse Production

On occasion, Alpine winter radish and Red Meat radish are sown in the greenhouse in 162-cell Winstrip trays three weeks prior to transplanting. Transplanting these crops is done by hand and allows for managing proper spacing at planting. These varieties do equally well when direct seeded.

Field Preparations

Radishes, rutabagas, and turnips are usually direct seeded into bare ground.

Direct Seeding

Radishes, rutabagas, and turnips are direct seeded with the MaterMacc VegiMacc in the field or with the Jang push seeder in the biointensive system.

For the VegiMacc, radishes are seeded with plate 144, 2.5 and sprockets 22-17 for 0.8-inch spacing. Red Meat will use plate 96, 2.5 and sprockets 12-19 for 2.5-inch spacing to reduce thinning. Purple Top White Globe turnips use plate 48, 1.0 and sprockets 22-17 for 2.4-inch spacing. Hakurei turnips use plate 144, 1.0 and sprockets 12-23 for 2.0-inch spacing. Rutabaga uses plate 48, 1.0 and sprockets 17-22 for 4.1-inch in-row spacing, to minimize thinning.

Purple Top White Globe turnips.

Rutabagas need four to six inches between plants, as they quickly fill in the spaces as they grow.

Family: *Brassicaceae*

In biointensive seedings, Hakurei turnips are seeded using seed roller YYJ-24 with four rows per bed at one-inch spacing. Alpine radishes are seeded using seed roller X-12 with four rows per bed at two-inch spacing. Other radishes are seeded using seed roller MJ-24 or X-24 at one-inch spacing.

Turnips and all radishes require 50 pounds of nitrogen per acre rate, while rutabagas require 100 pounds of nitrogen per acre rate. All required fertilizer is applied at time of seeding or planting.

Earliest seeding for radishes in the field is March 10, and latest is September 15. Red Meat radish is only grown in fall to prevent bolting. Rutabaga is also only seeded in fall, around the beginning of August, for harvest before Thanksgiving. Turnips are seeded in both spring and fall, and the earliest field planting date recommended is March 10, but the latest recommended seeding date is August 10.

Cultural Practices

Flea beetles will feed on leaves of all direct-seeded brassicas. The damage is tolerated on radishes and rutabagas, as the greens are not kept or consumed by CSA members. However, the turnip greens are a choice item. Covering turnips with 47-gram ProtekNet netting will protect the plants from flea beetle damage and preserve the quality of the greens. Hoops are used to hold the net above the plants.

Turnips are harvested quickly by pulling several plants loosely at one time.

Harvest

Radishes, rutabagas, and turnips are all harvested in a similar manner. Two workers move their way down the bed on either side, pulling the roots out of the soil. Sometimes the harvest is selective, particularly with rutabagas. Most radishes and turnips are harvested en masse. To pull the crops out of the ground, wrap hands around greens toward the base and lightly pull up. It is easiest to grab greens from several plants at once to pull them together. The greens should not be gripped tightly or they will bruise. Piles are made for the cleaning crew to work next.

Loose turnips are laid on the soil surface for bunching.

CROP HANDBOOK: RADISH, RUTABAGA, AND TURNIP

Family: *Brassicaceae*

Turnips are bunched in groups of five to six with rubber bands or twist ties.

When bunching, cleaners remove yellow or damaged leaves from the crops. Once cleaned, several roots are banded together at the base of the leaves, closest to the root top, with either a rubber band or twist tie. In radish bunches, eight to 12 radishes go into a single bunch. With Hakurei salad turnips, they should be one and a half to three inches in diameter at harvest, and four to six turnips will go into a bunch. Purple Top White Globe turnips are larger than salad turnips and best harvested at three to five inches in diameter. If bunching these, three turnips are sufficient. Usually, Purple Top turnips are not bunched, but greens are cut off to leave roots only. For any crops that have greens trimmed, only a quarter inch of stem should be left attached.

French breakfast radishes are laid on top of the soil for bunching.

CROP HANDBOOK: RADISH, RUTABAGA, AND TURNIP

Family: *Brassicaceae*

Harvested roots and bunches are packed into harvest bins. Bunches are best packed upright for efficient use of bins.

When it is a very sunny and hot day, no more than half of a bed of these crops should be harvested at one time. Leaving roots on top of the ground to sit in the sun while waiting for the cleaning and bunching crew will cause them to wilt. Bunches with greens are set in the shade under the harvest wagon once a bin is filled.

Bunched Rover radishes.

Watermelon radishes are piled for clipping greens.

Alpine winter radishes pulled from a high tunnel bed.

CROP HANDBOOK: RADISH, RUTABAGA, AND TURNIP

Family: *Brassicaceae*

Yield

Radish yields 0.50 to 0.75 bunches per row foot, on average. Rutabaga yields 1.2 pounds per row foot, on average. Hakurei turnips yield 0.40 to 0.70 bunches per row foot. Purple Top White Globe turnips yield one pound per row foot.

In CSA shares, turnips are given out one or two times in spring and one or two times in fall. Radishes are grown for the CSA in spring one to two times, and in the fall, members receive radishes one to two times, including one distribution of Red Meat radishes. Rutabaga and daikon radish are only in fall shares, as they mature much later than the regular CSA season.

Post-harvest Handling

Radishes, rutabagas, and turnip roots are all washed in the barrel washer. Items are sorted and packed into light-green bins and weighed.

Loose roots are washed in the barrel washer, sorted, and weighed.

CROP HANDBOOK: RADISH, RUTABAGA, AND TURNIP

Family: *Brassicaceae*

Bunched radishes and turnips are washed on the bunched washing station. However, if the soil is minimal, radishes can also be washed using the rinse conveyor on the circulation setting. Bunched radishes pack well into yellow or light-green bins. Bunched turnips fit better into light-green bins.

Bunched turnips are washed at the bunched washing station.

Bunched radishes are packed into bins after washing.

CROP HANDBOOK: RADISH, RUTABAGA, AND TURNIP

Family: *Brassicaceae*

Storage

Brassica roots and bunches are all stored at 32°F. Bins are covered with plastic pallet covers to retain moisture.

Easter Egg radish bunch.

Hakurei turnip bunch.

CROP HANDBOOK: RHUBARB

Family: *Polygonaceae*

Varieties

The Victoria variety is grown at UK-CSA. This variety has more green-colored stems with pink blush at the base, rather than pink coloring along the entire stalk.

Field Preparations

Rhubarb does not like to get overheated. The plot for perennial production is prepped with repeated shallow cultivations to minimize the weed seed bank. Rhubarb is planted with white landscape fabric in between plant rows to deflect heat absorption. Black landscape fabric is placed underneath white to control weeds. Fabric is secured with sod staples every foot.

Rhubarb requires 120 pounds of nitrogen per acre annually. Compost at a rate of 10 tons per acre and an annual required fertilizer amount is incorporated pre-planting. Annual fertilizer is applied next to the plant, but not directly on top of the crown. Fertilizer is lightly worked into the soil.

Transplanting

Rhubarb crowns are transplanted in March or early April, as soon as the ground can be worked. Crowns are buried with about one inch of the crown below soil level. Crowns are planted in rows five feet apart on center and three feet apart in-row.

Mature Victoria rhubarb.

Rhubarb is planted on white landscape fabric that has a layer of black installed beneath for weed control.

Transplanting rhubarb crowns into white landscape fabric.

Adding annual fertilizer around the plant's crown.

CROP HANDBOOK: RHUBARB

Family: *Polygonaceae*

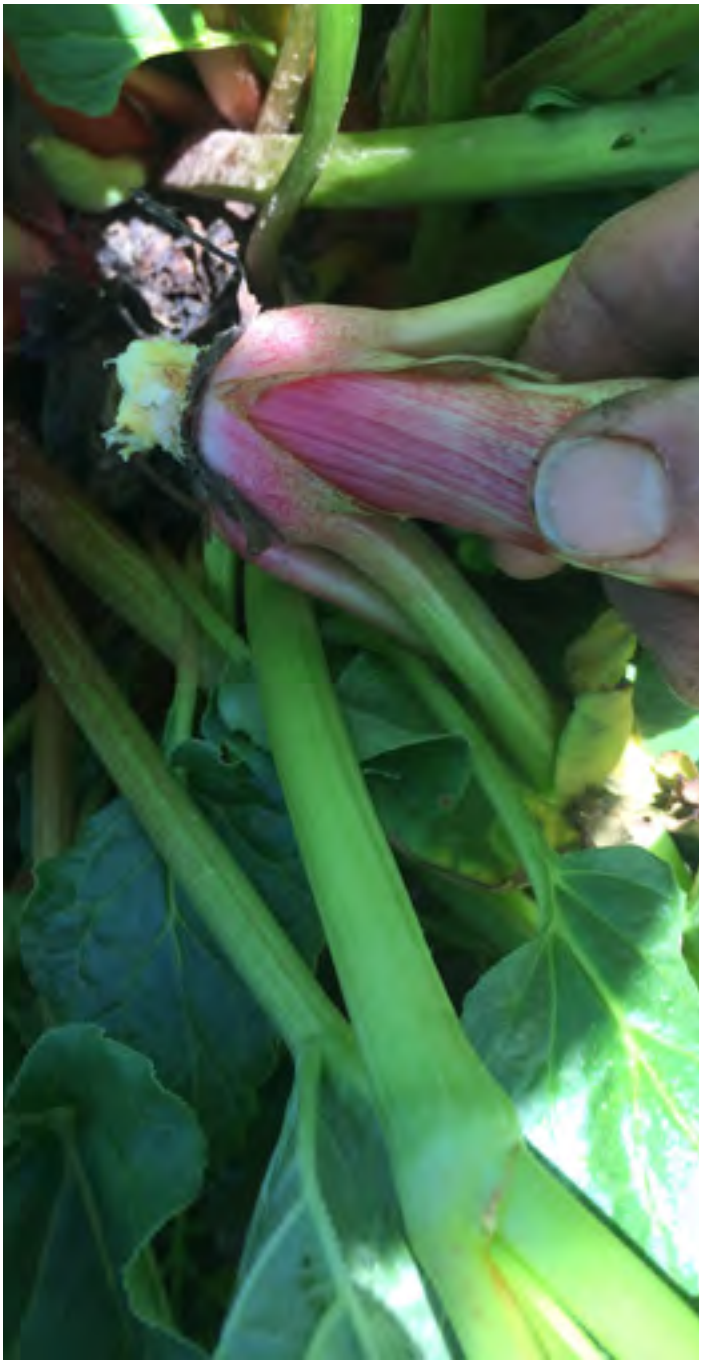
Cultural Practices

In-row, rhubarb is mulched to control weeds. Weeds between plants in-row are controlled through cultivation with scuffle and chop hoe as needed.

Rhubarb will sometimes set flower stalks in spring when under stress. Removal of each flower stalk at the base of the plant is necessary to ensure continued leaf production. Stalks should not be cut off. Instead, the base of the stalk is grabbed with two hands and pulled upward while rocking it from side to side, until it is dislodged from the crown. Care should be taken to make sure that the base of the stalk does not break off, as a clean removal of the entire stalk is necessary. The field is monitored weekly in spring to remove flower stalks.

Rhubarb flower stalk.

Some plants produce one or more flower stalks.



All flower stalks are removed by pulling them from base, as the entire stalk must be detached from the mother plant.

CROP HANDBOOK: RHUBARB

Family: *Polygonaceae*

Large rhubarb plants are divided in early spring, leaving at least five buds on original plant.

Japanese beetles are an occasional pest.

After four to five years of growth, rhubarb crowns can be divided. Another indication of needing to divide crowns is when the stalks themselves become numerous and thin. At least four to five buds are left on the original plant. A spade or shovel is driven vertically down into the root system to slice and divide. After retaining the original plant section of five buds or more, the extra plant may be divided into two or more clumps, with each clump bearing at least two to three buds. Divisions are replanted in holes left by plants that have died off, or they are planted to expand the area.

Japanese beetles are an occasional pest of rhubarb; however, usually no intervention is necessary, as only a few isolated plants are affected.

Harvest

Rhubarb stalks are harvested by hand, starting with a small harvest the second year and a full harvest in the third year. The largest and thickest stalks are picked from the plant and pulled from the base; ideally stalks are one inch across. Up to 50 percent of the stalks can be removed from a plant at a time. On average, eight to 12 stalks are removed from each plant. The leaves themselves of rhubarb are poisonous and are removed prior to washing and distributing. Workers use a lettuce field knife to chop the leaf off at the highest point on the stalk. Loose stalks are piled into harvest bins for transport out of the field.

Rhubarb stalks are harvested by hand, pulling them at the base of the plant.

CROP HANDBOOK: RHUBARB

Family: *Polygonaceae*

Rhubarb leaves are removed by a lettuce field knife. Stalks are gathered into harvest bins.

Rhubarb is harvested between May and October, one to three times a year.

Yield

Each stalk weighs around 0.2 pounds. Yield for rhubarb is 0.2 to 0.55 pounds per foot, or one to three stalks per row foot per harvest.

Rhubarb is included in spring shares, as well as late summer or early fall shares. Rhubarb is best paired with strawberries or green onions for making pie and salsa. Each share includes between one half-pound and one pound of stalks, or approximately five to eight stalks. Stalks can be distributed loose or banded together with a thick rubber band.

Post-harvest Handling

Rhubarb stalks are cooled and washed on the rinse conveyor with the circulation setting. Stalks are counted and laid into dark-green bins. A bin can hold 100 stalks. Stalks can be trimmed if they cannot lay down flat inside the bins.

Rhubarb stalks being washed in the rinse conveyor.

Storage

Rhubarb is stored at 32°F. Plastic pallet covers are placed over the bins inside the cooler. Rhubarb will benefit from being stored upright in one inch of water as well for maximum freshness.

Rhubarb stores for two weeks.

CSA members receive a half pound to one pound of bunched stalks in a share.

CROP HANDBOOK: SUMMER SQUASH, PATTY PAN, AND ZUCCHINI

Family: *Cucurbitaceae*

Varieties

Spineless varieties are preferred for ease of harvest, and they are also reliable performers.

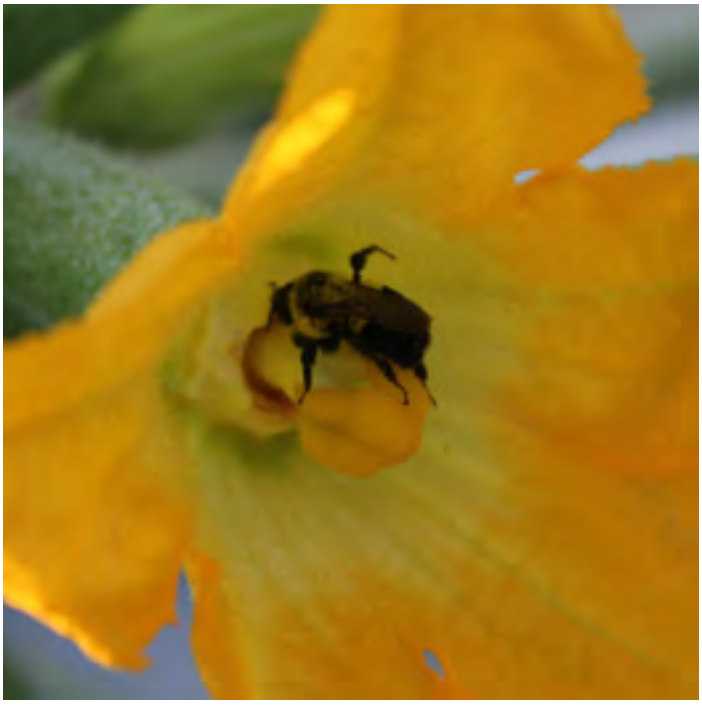
Yellow squash varieties grown include Lazor, Slick Pik YS 26, Multipik, and Smooth Operator. Zucchini varieties grown include Spineless King, Spineless Perfection, and Green Machine. Patty pan types grown are Y-Star, which is heavy yielding but turns green under heat stress, and Sunburst.

All of these crops mature in 25 to 35 days from transplant.

Yellow summer squash, ready for harvest.

Zucchini still has its flower bloom attached.

Patty pan squash, starting to grow.



Pollinators frequent the squash blooms.

CROP HANDBOOK: SUMMER SQUASH, PATTY PAN, AND ZUCCHINI

Family: *Cucurbitaceae*

Greenhouse Production

Summer squash, patty pan, and zucchini are hand-seeded into 72-cell Winstrip trays. Plants require only three weeks in the greenhouse, as they are fast growing and will get leggy quickly.

Squash plants only grow for three weeks in the greenhouse.

Summer squash at 10 days of growth.

Field Preparations

These crops are fast growing and short-lived, due to disease and insect pressures. For successful establishment, they are grown on aluminized plastic mulch beds. No living mulch is planted. Plastic beds are cultivated several times prior to planting. Each field holds six or seven beds spaced at least eight feet or seven feet apart respectively for summer squash, patty pan, zucchini, and cucumber.

Summer squash, patty pan, and zucchini require 100 pounds of nitrogen per acre. All required fertilizer is applied at time of plastic laying.

Transplanting

Earliest planting date is May 10, and latest is August 1. Summer squash is planted in early May and planned for four consecutive weeks of harvest, followed by a break of two to three weeks. A second planting occurs around late June for three to four more weeks of harvest in late July and early August.

Summer squash is transplanted using the Rain-Flo water wheel setter, in a single row per bed at 15-inch in-row spacing.

Cultural Practices

Plastic beds are cultivated one or two times after planting, until plants become too large to cultivate over them.

Summer squash, patty pan, and zucchini are routinely attacked by cucumber beetles and squash beetles. Kaolinite clay is sprayed on the leaves weekly, or as needed to deter feeding.

Common diseases on summer squash include powdery mildew and downy mildew. Fungicides are rarely applied since plants are so fast growing and short-lived.

Kaolinite clay is still visible on the summer squash planting and the plastic mulch.

CROP HANDBOOK: SUMMER SQUASH, PATTY PAN, AND ZUCCHINI

Family: *Cucurbitaceae*

Harvest

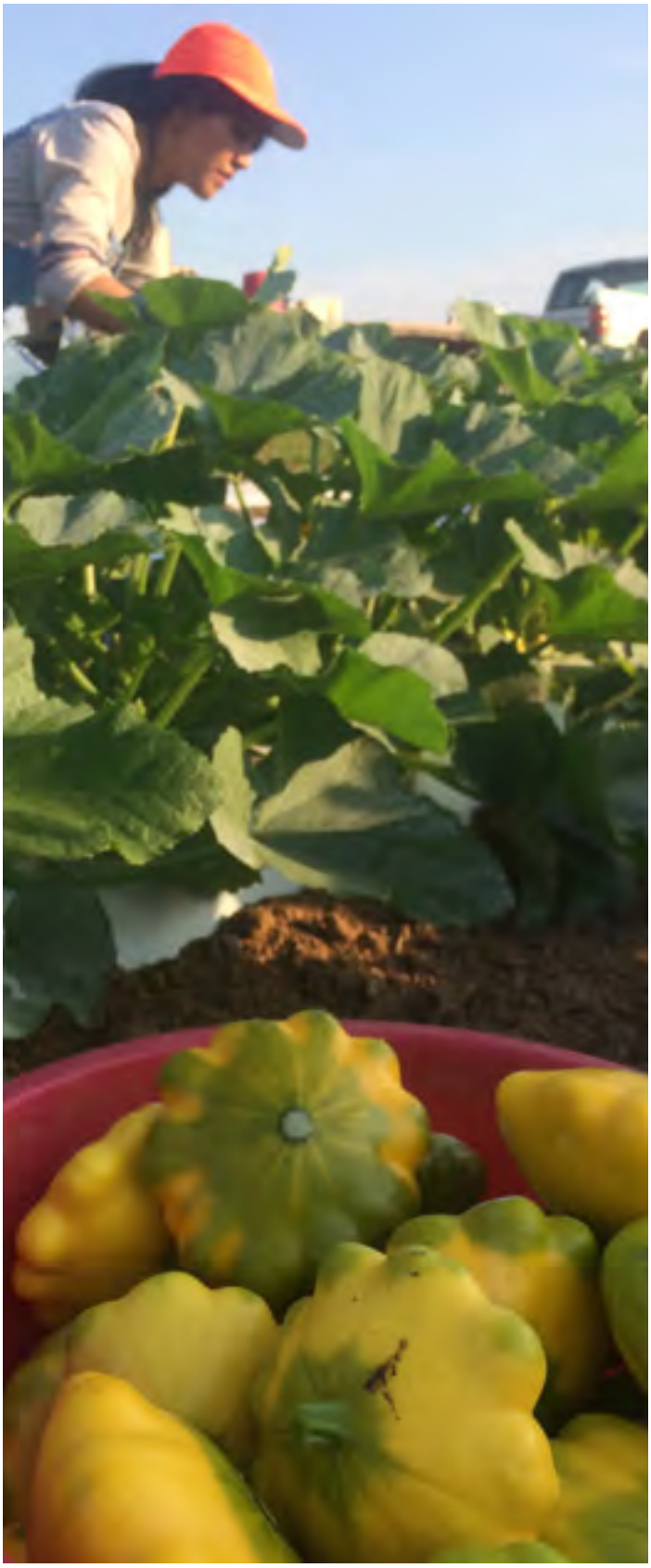
Summer squash and zucchini grow an average of one inch per day. They are harvested three times a week on Mondays, Wednesdays, and Fridays. Fruits are harvested using small harvest knives to cut the fruit at the stem from the plant. Workers must be careful to not let the plant's spines cause injury to the fruit's skin. Workers will benefit from long sleeves to prevent skin irritation during harvest. Two harvesters walk on either side of each bed.

A small knife cuts a zucchini at its stem.

The zucchini is gently placed in a red bucket.

CROP HANDBOOK: SUMMER SQUASH, PATTY PAN, AND ZUCCHINI

Family: *Cucurbitaceae*



Patty pan harvest.

Yellow summer squash harvest from plants growing out of the clay protectant.

CROP HANDBOOK: SUMMER SQUASH, PATTY PAN, AND ZUCCHINI

Family: *Cucurbitaceae*

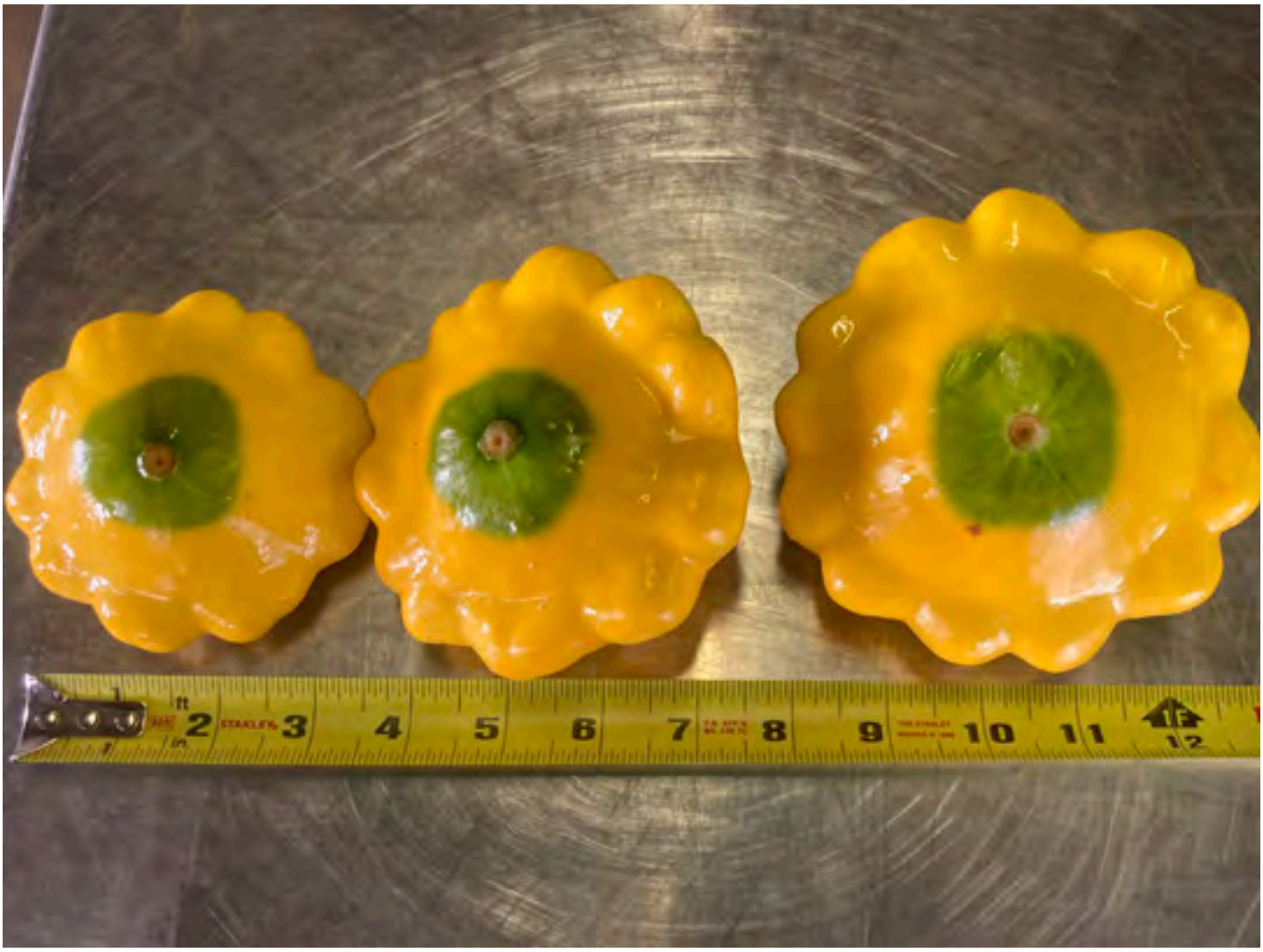
Summer squash and zucchini are harvested when five to seven inches long, and patty pan when three to four inches in diameter. Oversized squashes and zucchinis are removed from the plants and tossed in the drive rows. Flowers that are still attached to the end are pulled off at harvest, as they may not dislodge during washing. Harvested crops are gently placed into red buckets. Full buckets are handed off between workers and set down at the edge of the field for pick up with the harvest wagon. The conveyor is also sometimes used to pick up buckets after harvest.

Workers are passing buckets of squashes to field edge for pick up.

Zucchini measures six to eight inches at harvest. Yellow summer squashes may be harvested as small as five inches.

CROP HANDBOOK: SUMMER SQUASH, PATTY PAN, AND ZUCCHINI

Family: *Cucurbitaceae*



Patty pan squashes vary in size from 3.5 inches to five inches in diameter.

Yield

Yellow squash yield 0.8 to 1.0 fruits per row foot; zucchini yields 0.6 to 0.9 fruits per row foot; and patty pan squashes yield 1.0 to 1.2 fruits per row foot.

Yellow squash and zucchini are given out in CSA shares three to five times in the early season. For the second planting of yellow squash, zucchini, or patty pan squashes, they are given out for another three to four weeks. Each share receives one to four squashes per distribution.

CROP HANDBOOK: SUMMER SQUASH, PATTY PAN, AND ZUCCHINI

Family: *Cucurbitaceae*

Post-harvest Handling

Summer squashes are all washed in the brush washer. After washing, squashes are sorted and counted into light-green bins. Bins are labeled with the number per bin, which faces out when they are stacked in the cooler.

Squashes are loaded into the brush washer for washing, sorting, and packing.

Bins of squashes are labeled with their quantity facing outward for double checking and dividing harvests for CSA locations.

CROP HANDBOOK: SUMMER SQUASH, PATTY PAN, AND ZUCCHINI

Family: *Cucurbitaceae*

Storage

Summer squashes are optimally stored at 41°F to 50°F. No plastic pallet covers are required.

Summer squashes are stored for one to two weeks.

Green Machine zucchini.

Multipik yellow summer squash.

Sunburst patty pan squash.

CROP HANDBOOK: SWEET POTATOES

Family: *Convolvulvaceae*

Two Covington sweet potatoes, freshly dug.

Varieties

Sweet potato varieties grown include Covington, Orleans, and Murasaki. Covington is the preferred variety. Murasaki is a Japanese variety with purple skin and white flesh; tubers are smaller and yield is overall much less than either Covington or Orleans.

Sweet potatoes are purchased as slips, which are vegetative shoots from a sweet potato tuber. When the field is not ready, the slips can be held in a 55°F cooler for one to three days by wrapping roots in damp paper towels. If the slips need to be held longer, they can be heeled in a trench for holding up to a week.

The slips on left were compromised during transit, most likely from heat. The rotted slips were not planted. Normal slips look like those on right.

CROP HANDBOOK: SWEET POTATOES

Family: *Convolvulvaceae*

Slips wrapped in damp paper towels are being held in the cooler until planting.

Slips are heeled in, the practice of covering the plant roots temporarily for protection before transplanting to their permanent location.

Field Preparations

Sweet potatoes are planted on black plastic mulch. No living mulch is grown, due to the rapid vining of the sweet potato plants.

Sweet potatoes require 40 pounds of nitrogen per acre. All fertilizer required is applied pre-planting at time of plastic mulch installation.

CROP HANDBOOK: SWEET POTATOES

Family: *Convolvulvaceae*

Newly transplanted sweet potato slips on black plastic mulch.

Transplanting

Sweet potatoes are planted with one row per bed and nine-inch in-row spacing, using the Rain-Flo water wheel setter. Slips are spindly, so care is taken not to bend and break them. When bed top is moist underneath, it is easy to push the slip into the soil and pack soil around it to ensure it is secure.

Earliest planting date is May 10, and the latest is June 10. Sweet potatoes are usually planted around May 20–25.

Cultural Practices

Plastic mulch beds are cultivated with the plastic cultivator two to three times. Once the vines have grown off the bed tops, a final cultivation can occur, which will rip some of the leafy vines, but the plants are quite vigorous and can withstand this late cultivation disturbance.

A sweet potato slip putting on new growth.

CROP HANDBOOK: SWEET POTATOES

Family: *Convolvulvaceae*

The vines are spreading quickly, but bare soil is still visible in the aisles. These beds can be cultivated in one final pass. Some vines will be torn, but the crop will not be harmed.

Very few insect pests and diseases harm sweet potatoes. The primary pest of sweet potatoes are voles that live underground and chew on mature tubers. Trapping in spring and crop rotation are the primary methods for addressing vole issues. Eliminating plastic mulch and growing sweet potatoes on bare ground is another method.

Harvest

Sweet potato greens can be harvested when vines are full, in July or early August, to get a second crop for CSA shares. Clip individual leaves at the ends of vines to get the more tender leaves. Leaves should not be washed, as they are easily damaged and will become water-soaked. Bundle or bag greens and keep in cooler at 32°F until distribution.

Leaves from flowering sweet potato vines are harvested selectively into bins in early August.

A handful of sweet potato vine leaves can be included in CSA shares in midsummer.

CROP HANDBOOK: SWEET POTATOES

Family: *Convolvulvaceae*

Checking on sweet potato tuber sizing. Each plant should produce one to two large sweet potatoes and a few smaller ones. These tubers are ready for harvest.

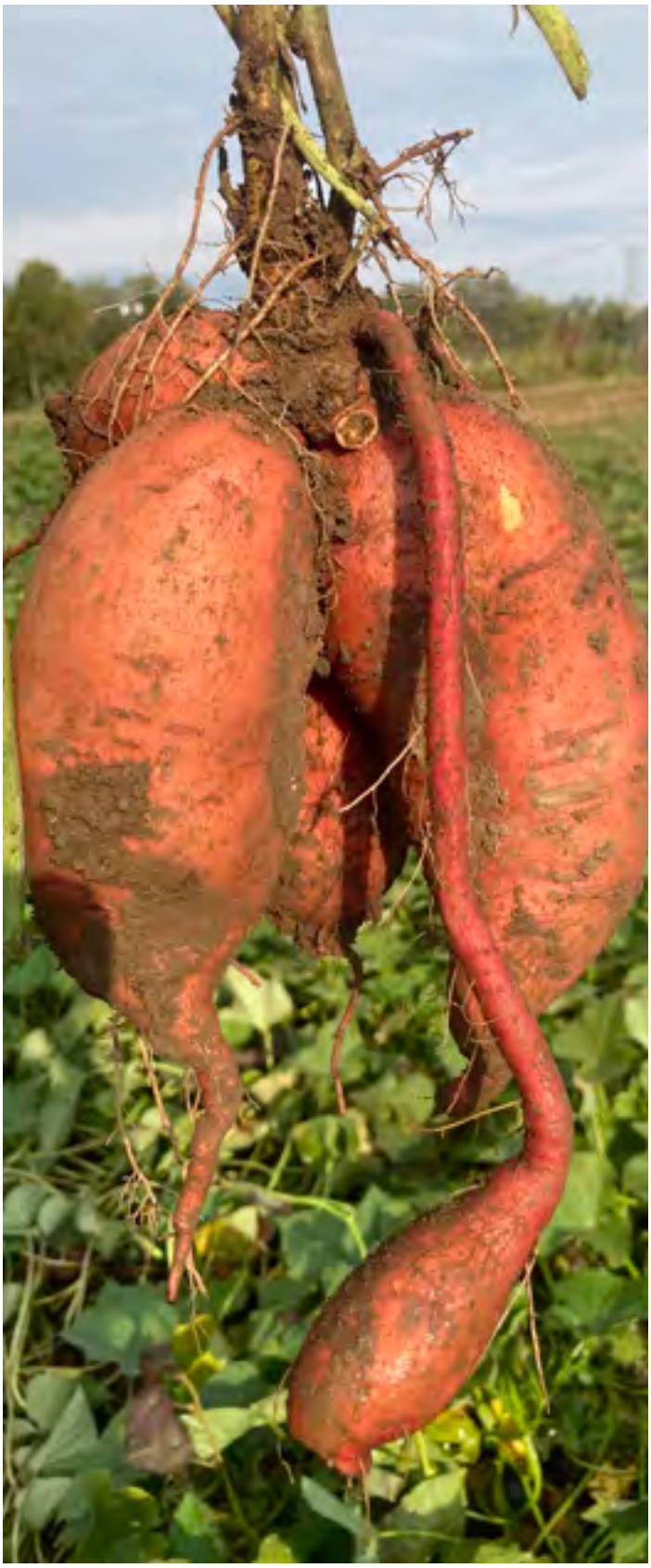
In late August or early September, plants are selectively dug with a hand shovel to check for tuber sizing. Sweet potatoes can quickly grow to beyond target size if not harvested in a timely fashion.

When tubers have reached mature size, sweet potato vines above ground are mowed with a flail mower atop the beds. Plastic beds are lifted with a Rain-Flo Plastic Challenger Model 1800 mulch lifter.

Black plastic and vine residue sits on top of the tubers after mulch is lifted.

CROP HANDBOOK: SWEET POTATOES

Family: *Convolvulvaceae*



Tubers still attached to vines can be hand-pulled from the vines.

Red buckets are used to hold the sweet potatoes that are picked up by hand. Workers wear nitrile gloves to prevent sweet potato sap from staining hands. Buckets are dropped along the field edge for easy grabbing and filling. Harvesters locate the top stem, which may still be emerged through the plastic hole. Beneath the plastic, attached to the stem, will be the sweet potatoes. Individual potatoes are twisted off by hand to separate them from the stems. Potatoes are placed in the buckets. Some potatoes will have dislodged from the stems and may remain in the soil. Harvesters use their hands to dig beneath the lifted plastic and search for any roots still buried.

All sweet potatoes are inspected at harvest. Significant vole damage is one cause to cull the fruit. Smaller bite marks on the potatoes are tolerated and sold as "seconds." A clean cut on the potato will heal over during curing. Any potatoes damaged by the mulch lifter are discarded. Any potatoes with soft spots are usually readily apparent and discarded.

While edible, CSA members do not want overly large sweet potatoes.

CROP HANDBOOK: SWEET POTATOES

Family: *Convolvulvaceae*

Harvesters fill red buckets with sweet potatoes before being unloaded into a macro bin.

Once red buckets are full, the harvest wagon is driven down the drive row and buckets are passed over to the wagon. Each bucket is dumped into a macro bin.

Yield

Sweet potatoes grown with one row per bed yield on average three pounds per row foot. Sweet potatoes can be grown with two rows per bed; however, the yield per row foot will be reduced.

Sweet potatoes are given out three times in CSA shares. The first share of the year will receive sweet potatoes that have been stored over winter. The other two distributions are in the last month of shares, after the curing process has been completed. Sweet potatoes are also a staple crop for Thanksgiving and fall CSA shares. Each share receives three to four pounds of sweet potatoes at a time.

Plastic mulch can be pulled up prior to loading the potatoes in buckets for easier harvest. Only beds that will be promptly harvested are mowed at one time.

CROP HANDBOOK: SWEET POTATOES

Family: *Convolvulvaceae*

Sweet potatoes after curing in the greenhouse are weighed and packed in brown paper bags.

Post-harvest Handling

Sweet potatoes are not washed, but they do require curing. Macro bins are lidded and taken to the greenhouse for curing. The ideal temperature for sweet potatoes to cure is 70°F. At lower or variable temperatures, the curing process will be slowed. Sweet potatoes are cured after 10 to 14 days and then handed out in CSA shares. Once cured, the sweet potatoes will have developed their sugars, the skins will be firm, and they will be ready for storage.

For CSA distribution, sweet potatoes are weighed into brown paper bags. Paper bags are folded down and set in dark-green bins. About 12 to 14 bags will fit in a bin, split between two layers.

Storage

Sweet potatoes are ideally held at 55°F to 60°F with high (80 to 85 percent) relative humidity. A temperature-controlled environment is preferred for long-term storage. Macro bins are stored over winter in a climate-controlled area, or in UK-CSA's Cooler 2 set at 55°F, so as not to suffer cold damage. Sweet potatoes will store for six to nine months or more. The bins are checked during winter for any molding or decaying tubers; tubers that are decaying are removed from the storage bins.

CSA members receive three to four pounds of sweet potatoes for each share distribution.

CROP HANDBOOK: TOMATOES

Family: *Solanaceae*

Varieties

The majority of tomato varieties grown for CSA are indeterminate in order to capitalize on the longest growing season. At UK-CSA, tomatoes grown include hybrids, heirlooms, and paste, as well as varieties suited for you-pick. CSA customers enjoy the flavor from heirlooms, but these varieties are more challenging to grow. Therefore, offerings are diversified with more reliable varieties. The tomato mix breakdown for all plantings is as follows: hybrids are 40 to 45 percent, heirlooms are 30 to 35 percent, and paste are 25 to 30 percent. You-pick varieties are not included in these percentages. You-pick types include cherry, grape, cocktail and saladette tomatoes that are smaller and better suited for you-picking.

Hyrid varieties regularly grown include Big Beef, Park's Whopper, New Girl, Mountain Merit, Mountain Princess, Defiant, and Chef's Choice Orange.

Super Choice, Costoluto Genovese, German Johnson, Vinson Watts, Pineapple Premier, Striped German, and Valencia varieties are grown for heirlooms.

Amish Paste, Speckled Roman, San Marzano II, and Plum Regal varieties are grown for paste tomatoes.

Yellow Pear, Sun Gold, Sun Sugar, Pink Champagne, Juliet, Green Zebra, Glacier, Lollipop, and Matt's Wild Cherry varieties are grown for you-pick.

The earliest tomatoes ripen in 55 to 60 days. The larger beefsteak and slicing tomatoes generally ripen in 65 to 75 days. Some larger heirlooms and paste tomatoes may take as long as 78 to 85 days. All days to maturity are from transplant.

Greenhouse Production

Tomatoes are started in 162-cell Winstrip trays, with two to three seeds per cell. Tomatoes will benefit from being on a heated mat at 70°F until they germinate, after which they should be taken off the heat mat. The tomatoes are potted up into 50-cell Winstrip trays when true leaves emerge on the seedling. Plants are typically ready for transplanting in five weeks.

Tomato varieties grown at the CSA.

Varieties planted in the you-pick field.

CROP HANDBOOK: TOMATOES

Family: *Solanaceae*

Teff living mulch being established.

Tomato transplant.

Field Preparations

Early tomatoes are planted on black plastic mulch. Later tomatoes can be grown on either black or white plastic mulch. When grown in the high tunnels, black woven landscape fabric is used instead of single-use plastic mulch. Tomato beds in the field are spaced 10 feet apart, center to center, for air flow. Teff living mulch is established between the beds.

Tomatoes require 125 pounds of nitrogen per acre. Two-thirds of the nitrogen requirements is applied pre-planting at time of plastic laying. The remainder is fertigated after eight to 10 weeks of growth.

Transplanting

Tomatoes are transplanted after last frost, sometime after April 25. A succession planting is planted three to four weeks later, or any time prior to July 1.

In the field, tomatoes are planted using the Rain-Flo water wheel setter. Plants are in a single row, spaced 18 inches apart in-row. A gap of two plants is left in the middle of the bed (150 feet from end) to act as a pass-through for workers. In high tunnels and Haygrove systems, plants are hand-planted and spaced 24 inches apart in-row. Five rows will fit the width of either structure.

The transplant is buried as deeply as possible, up to the first set of leaves if able. The deeper the plant, the stronger the root system that will develop.

Cultural Practices

Shortly after planting, T-posts are installed into the bed. At the beginning of every season, T-posts are sanitized either by dunking in a bleach solution in a bucket loader or using a power washer to spray off the T-posts with a bleach solution. This helps to ensure no pathogens can persist if they have overwintered on residual soil still left on the metal T-posts. In addition, reusable landscape fabric is sprayed or soaked in a bleach solution before installation in the high tunnel.

T-posts at installation are placed after every two plants. Workers installing T-posts must make sure the drip irrigation line buried in the bed is not punctured. All T-posts face the same direction. The posts are centered with the row of plants, which will help with tomato tying.

Tomatoes are tied using the Florida weave. See **SOP: Tomato Tying**.

Tomatoes are tied weekly as they grow, and sometimes more frequently during growth spurts. Each successive tie is spaced about four inches above the preceding one. The tomato stem must be captured and held up by the twine during tying. The next strings are simply run on the outside of the plants and held in place by circling the T-posts. Plants are

CROP HANDBOOK: TOMATOES

Family: *Solanaceae*

Metal T-posts being sanitized before installation.

Workers wear ear protection when installing T-posts, spaced two plants apart.

Tomatoes are tied up with twine weekly.

sandwiched between two lines of twine, with one on front and one on back; no crossover is made. It takes about 15 to 20 minutes to completely tie a half row of 150 feet of tomatoes. Workers stop the tying at the midpoint in the field and circle back to tie down the other side, in order to preserve the two-plant gap at the middle of the bed for a pass-through.

When determine tomato varieties are grown, these plants do not grow nearly as tall as indeterminate types. It is advantageous for tying purposes to group all determinate varieties together, as they will be tied similarly. The height of plants of indeterminate varieties will also vary from variety to variety. The "rampancy," or final plant heights, of tomatoes is noted for the tomato varieties chosen. For field plans, tallest plants are situated on the north and west sides of the fields. Tallest plants are grouped in the same row if possible, according to ascending rampancy. (See the Pam Dawling rampancy rating list.)

In addition to tying tomato plants, tomatoes are suckered to encourage plant vigor. Suckers emerge in the crotch angles of the plants. Sucker at the first sign of flower blossoms on the plants. The first bloom set, which is closest to the bottom of the plant, is located first. One sucker below that first bloom cluster is left on the tomato plant. All other suckers below that

The flower clusters are small and yellow. They are used as a reference point to remove suckers below them.

Family: *Solanaceae*

one are removed. In addition, any suckers emerging from the base of the plant at soil level are removed. Removal is done by hand, by pinching. Larger suckers are best removed by pruners. Suckering may be needed weekly to keep plant vegetative growth in check.

Tomatoes are susceptible to many types of foliar and soilborne diseases. The primary tomato issues are early blight, late blight, Cercospora leaf spot, and bacterial speck. In addition, nutrient and water imbalances can cause blossom end rot, yellow shoulder, catfacing, cracking and splitting. The best organic practices are prevention of issues that are spread by wind and water. Susceptible tomato varieties, like heirlooms, are grown under cover in a Haygrove or high tunnel system to prevent these problems from arising. The tunnel environment also allows for an earlier planting date for the first round of tomatoes. Tunnel tomatoes are rarely sprayed with fungicides or insecticides.

In open-field production, a protective copper spray is applied every seven to 14 days, or as needed, e.g. prior to a rainfall event. In addition, some biofungicides are efficacious at improving plant vigor and performance. Some of these can be used in conjunction with protective sprays. A 10-foot bed spacing is followed to maximize air flow. If disease issues intensify, plants can be spaced 24 to 36 inches apart for more air flow. In addition, plants are rotated away from other solanaceous crops. The first and second tomato plantings are situated in different fields to reduce disease pressure on the later-planted tomatoes.

Grafting tomato plants is one way to mitigate soilborne diseases for tomatoes grown under cover, when rotation options are limited. A disease-resistant rootstock is selected to pair with susceptible plants. Successful grafting relies on a stable graft union by matching plants with similarly sized stems. Therefore, some trials are recommended each year to ensure the rootstock and susceptible tomato varieties will align in their growth stage for successful grafting. Rootstock varieties include Shin Cheong Gang, Maxifort, and Estamino; however, our limited trials have shown that Estamino is slower growing than most of the susceptible fruiting tomatoes and should be started earlier than the susceptible variety.

Primary pests that require plant monitoring include aphids (look under plant leaves, use insecticidal soap to control as needed); tomato hornworm (frequently late in the season and will be parasitized, so damage is minimal); and tomato fruitworm (use Bt for late-season tomatoes to control).

When the field is being taken out of production, tomato string is removed first before clearing the field. Workers use a pocket knife or hand shears while walking down every tomato row and slice the string along the edge of every other T-post, from top to bottom. Workers then walk to the T-post in between each cut one and pull the string out. After all string has been removed and disposed, T-posts are removed using a T-post remover. Gloves are recommended. At this point, plants are mowed, and then plastic is lifted and removed as usual.

While grasshoppers are frequent visitors in the tomato field, they do not cause significant damage.

The green hornworm is parasitized. These worms are seldom a pest issue due to biocontrol organisms like parasitic wasps.

CROP HANDBOOK: TOMATOES

Family: *Solanaceae*

Harvest

Tomatoes are harvested twice a week, on Mondays and Thursdays. Ideal ripeness is 50 percent or more.

Tomatoes are pulled gently off the vine. The calyx of the stem is removed if it stays attached to the tomato at harvest, as this can degrade in storage. Tomatoes are always set gently down on their shoulders in the bins.

Hybrids and paste tomatoes are stacked in two layers in bins. Heirlooms are only stacked in a single layer. When double stacking, less-ripe tomatoes are placed on the bottom layer.

Yellow bins or bread trays are used to hold tomatoes; yellow bins can hold two layers, while bread trays can only hold single layers and are best used for heirlooms.

Harvesters start at one end of the field.

Tomatoes are stacked in single layers in bread trays.

CROP HANDBOOK: TOMATOES

Family: *Solanaceae*

A sled is used to hold tomato harvest bins.

An ATV can fit between tomato beds to pick up full bins, if needed.

Bins are carried through the field or pulled with a sled tied to the harvester's belt. The sled will allow both hands to be free for harvest. When bins are full, they are placed on top of the plastic mulch shoulders in the shade for pick up by ATV, or they are carried to the harvest wagon using the plant gap at the middle of the rows. At the harvest wagon, each bin is weighed and labeled with the weight. The weight is recorded in the harvest log. Tomatoes are kept shaded by placing an empty bin on top of the full bins.

Yield

Paste tomatoes average 10.4 pounds per plant. Hybrid tomatoes average 10.2 pounds per plant. Heirloom tomatoes average 9.2 pounds per plant. These averages represent marketable fruit.

Each year, around 1,285 tomato plants are grown for a 250-member CSA. Over 1,000 of these are planted in an open-field environment, while around 275 are planted under cover in a Haygrove or high tunnel system. These plants produce fruit totaling more than 13,000 pounds or more each year. Tomatoes are given to CSA members for 12 to 14 consecutive weeks, from July to October. Over the course of a season, CSA members receive around 50 pounds of tomatoes. Each week, members receive between one and six pounds of tomatoes. The goal is to deliver 2.5 to 3.5 pounds a week, but some weeks are lighter, and others are heavier as plants ramp up and when the second planting starts to produce more.

CROP HANDBOOK: TOMATOES

Family: *Solanaceae*

Post-harvest Handling

Tomatoes are not washed. However, they are wiped down with a dry cloth if needed.

Some sorting of tomatoes harvested before the day of distribution is required. Any tomatoes that are 80 percent ripe or more with bruising, cracks that are not fully healed, or other deformities are sorted out of the marketable CSA fruits and set aside to be sold as "seconds" for canning. Boxes of 25 pounds of canning tomatoes are assembled.

Storage

Tomatoes are not refrigerated below 50°F. However, they are safely stored at 55°F. Storage is beneficial for tomatoes to minimize loss and damage. If they are stored at 55°F, some condensation may occur when the tomatoes are removed from storage depending on ambient air temperatures. To minimize condensation, tomatoes are pulled out the night before packing them for the CSA. Stacks are kept at ambient temperature in the packing shed. If small mammals are a concern, the stack of tomato bins is covered with a plastic pallet cover and the edges are tucked under bins to keep any unwanted visitors out.

Red, ripe tomatoes.

Tomatoes are covered with plastic in the packing shed prior to distribution.

Underripe tomato, which is not ready to harvest.

CROP HANDBOOK: TOMATOES

Family: *Solanaceae*

Tomato at 50 percent ripeness. All tomatoes must be at this level of ripeness or greater at harvest.

Hybrid and paste tomatoes at 75 percent or more ripeness.

CROP HANDBOOK: WATERMELON

Family: *Cucurbitaceae*

Varieties

Only diploid watermelons, which contain seeds, are grown. Triploid, or seedless, watermelons are not grown due to space requirements for non-productive pollenizer plants. Sugar baby watermelons are round and smaller, at seven to 10 pounds each, which is ideal for CSA shares. They are very sweet but do contain many seeds. Blacktail Mountain is the favorite variety.

Yellow- and orange-flesh watermelons are specialty types. New Orchid and Sorbet Swirl have performed well. Flavor is very good for both.

Larger watermelons are seldom grown, due to storage limitations. Both Sangria and Moon and Stars heirloom varieties have produced nice melons when larger types have been grown.

Watermelons mature in 75 to 80 days from transplant.

New Orchid watermelons have a yellow flesh.

Blacktail Mountain sugar baby watermelons.

Moon and Stars heirloom watermelons may weigh 30 to 40 pounds apiece.

CROP HANDBOOK: WATERMELON

Family: *Cucurbitaceae*

Greenhouse Production

Watermelons are hand-seeded into 72-cell Winstrip trays. Seedlings are prone to aphid attacks, so plants are monitored closely. Plants require four weeks in the greenhouse.

Field Preparations

Watermelon is grown on black plastic mulch beds. No living mulch is planted. Plastic beds are cultivated several times prior to planting. Each field holds six or seven beds for melons, spaced at least eight feet or seven feet apart respectively.

Watermelon requires 120 pounds of nitrogen per acre. All fertilizer required is applied at time of plastic laying.

Transplanting

Earliest planting date is May 5, and latest is July 1.

Watermelons are transplanted using the Rain-Flo water wheel setter, in a single row per bed at 24-inch in-row spacing.

Cultural Practices

Plastic beds are tractor-cultivated two to three times after planting, until vines spread off the bed. A final cultivation can be done by manually moving any vines that have fallen off the bed top back onto the bed. After this final cultivation, the plant is left to grow into the rows and shade out weeds. The field is monitored for larger weeds. Any larger weeds are selectively removed by hand or chop hoe. Workers are careful when walking into the field to minimize damage to fruits or vines.

Watermelons are much hardier than cantaloupes. Crops are monitored closely when young for aphids. Beneficial insect releases are sometimes made, but without netting there is no guarantee the insects will stay nearby. If available, netting is used on plants when small and removed when ready for pollination. If aphids are problematic on young watermelon plants, insecticidal soap is sprayed to knock the population back.

Irrigation is withheld in the last two weeks of maturation to increase melon sweetness.

A baby watermelon begins to grow.

CROP HANDBOOK: WATERMELON

Family: *Cucurbitaceae*

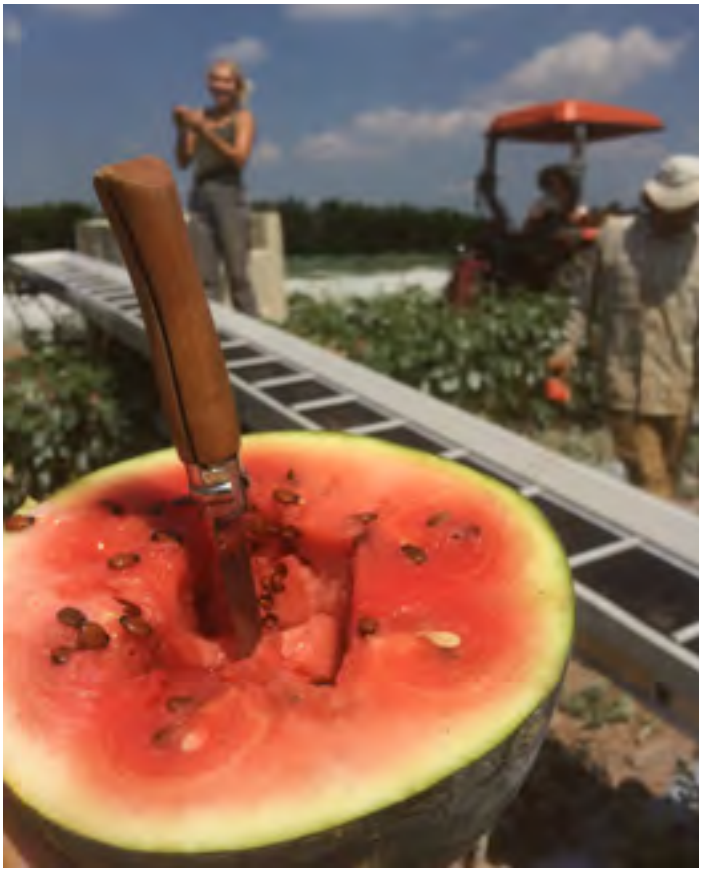
Harvest

Watermelons are harvested in the field using the harvest conveyor. The conveyor wagon should be preset with two macro bins situated on either side of the conveyor prior to being taken to the field. Workers walk in between each bed and check both beds on left and right, as well as the area in between, for melons ready to harvest. Harvest is selective for ripe watermelons.

Harvest indicators include the size of melon, a hollow sound when melon is thumped on the exterior, and a desiccated tendril located at the first node away from the fruit's stem. There will also frequently be a yellow spot on the bottom of the melon, which is an indication of its maturity. To determine the best melon size for harvest, two to three melons of various sizes are cut open in the field to check for internal coloration. Flesh should have full, deep color and taste sweet.

A yellow spot on the bottom of the melon is another harvest indicator.

A dried tendril is one harvest indicator.



The taste test is always a good method to determine readiness.

Family: *Cucurbitaceae*

Melons are removed from plants by hand, by gently pulling the stem away from the top of the fruit. Melons are gently placed individually onto the conveyor. The conveyor will carry the melons to the harvest wagon, and workers place melons into macro bins. Melons should not be dropped into the bins, as they can crack. When field conditions do not require melons to be washed, they are counted at time of harvest by the worker placing them into the macro bins.

A conveyor helps with transferring melons to macro bins.

Yield

Sugar baby watermelons yield 0.75 to 0.85 fruits per row foot. Specialty melons and larger varieties may only produce 0.25 to 0.30 fruits per row foot.

Watermelons are given out in CSA shares two to three times a year. Each share receives one melon per distribution.

Post-harvest Handling

Watermelons are washed in the brush washer to remove soil on the exterior skin, if needed. If washing is not necessary, watermelons are kept in a clean macro bin and moved to the cooler for room cooling.

Storage

Watermelon is optimally stored at 55°F. They are very sensitive to ethylene and need to be kept away from ethylene-producing fruits and vegetables. After field heat is removed, plastic pallet covers are placed over the tops of the macro bins.

Blacktail Mountain variety of watermelon can be stored for three to four months under optimal conditions. This storage life allows for flexibility with share distribution. However, space for one to two macro bins in the cooler is required to keep them housed.

Most other watermelons store well for two weeks.

Watermelons are kept in macro bins and moved into the cooler using a pallet jack.

CROP HANDBOOK: WINTER SQUASH AND PUMPKIN

Family: *Cucurbitaceae*

Varieties

Only Moschata and Pepo types of winter squash are grown at UK-CSA, but several varieties within these genuses are grown annually. The preferred hallmark varieties include Waltham and Honeynut (butternut); Tiptop and Table Ace (acorn); Delicata JS and Jester (delicata); and Pinnacle or Spaghetti Squash (vegetable spaghetti or spaghetti squash).

Most winter squashes take 85 to 105 days to maturity from direct seeding, or 75 to 90 days from transplant.

Pie pumpkin varieties include Cinnamon Girl PMR and Baby Pam. Pie pumpkins mature in 85 to 99 days from direct seeding, or 75 to 89 days from transplant.

Greenhouse Production

Winter squashes are hand-seeded into 72-cell Winstrip trays in ProMix media, instead of our standard potting media. ProMix is used for these crops because of their fast and vigorous growth, which does not depend upon robust fertility in the tray. Winter squash and pumpkin only require three weeks in the greenhouse, as they are fast growing and will get leggy quickly.

Field Preparations

Winter squash can be grown on white plastic mulch, but due to insect pressures they are best grown on aluminized plastic mulch beds. Row covering at time of planting will also be beneficial, but it is not required. Plastic beds are cultivated several times prior to planting. Each field holds six or seven beds for winter squashes, spaced at least eight feet or seven feet apart respectively.

Both winter squash and pumpkin require 100 pounds of nitrogen per acre. Granular fertilizer required to meet crop needs is all applied at time of plastic laying.

Transplanting

Earliest planting date is May 5, and latest is June 15 for pie pumpkin and July 1 for other winter squashes.

Winter squashes are planted with the Rain-Flo water wheel setter, with one row per bed at 15-inch in-row spacing. Pumpkins require more space and are planted with 30-inch in-row spacing.

Winter squash only grows in the greenhouse for three weeks.

Winter squash is transplanted with a water wheel transplanter.

CROP HANDBOOK: WINTER SQUASH AND PUMPKIN

Family: *Cucurbitaceae*

The foliage is no longer protecting this spaghetti squash from sunscald.

Cultural Practices

Netting will help all winter squashes when available, but pumpkins get priority for netting. All winter squashes are grown on aluminized mulch for insect control when able. Any nets are removed once plants are flowering for pollination.

Major pests of winter squash are cucumber beetles and squash beetles. Kaolinite clay is sprayed on the leaves weekly, and more frequently as needed after heavy rains, to deter feeding.

Powdery mildew is the biggest disease issue. Fungicides are applied regularly, since plants have to survive for a very long time. When plant foliage dies back, fruits are at risk of sunscald and are harvested quickly.

Plastic beds are tractor-cultivated until plants vine out off the beds, or until plants are too tall for the cultivator to pass over top of them.

Harvest

Winter squashes are harvested when the skin has developed 75 percent or more of its coloring. If plant foliage has begun to die back, fruits are susceptible to sunscald and are taken early. Fruits will ripen further in storage.

Winter squashes are harvested using pruners. Workers may want to wear gloves and long sleeves to prevent skin irritation from the plant foliage. A small stem of one-half to one inch is left on each squash; pumpkins can have a longer handle of two to three inches. Workers walk on either side of each winter squash bed. Squashes are grouped into piles every five to 10 feet on top of the bed. After the field is harvested, squashes are picked up with the harvest conveyor. Workers follow behind the conveyor to place the squashes on top of the belt. The wagon is pre-set with two macro bins, and squashes are sorted by type into the macro bins and counted. Best practice is to set the squashes into the bins and not drop them.

Squashes are clipped from vines and stacked on top of beds.

CROP HANDBOOK: WINTER SQUASH AND PUMPKIN

Family: *Cucurbitaceae*

Squashes are placed on the conveyor and counted into macro bins.

Yield

Delicata varieties yield up to 1.8 to 3.0 fruits per row foot. Spaghetti squash yield 0.4 to 1.25 fruits per row foot. Acorn yield 0.9 to 1.0 fruits per row foot. Butternut yields 2.0 to 2.5 fruits per row foot. Pumpkin yields 0.6 to 1.3 fruits per row foot.

Each type of squash is destined for CSA shares once, with the exception of butternut, which is included twice. Overall, winter squashes are included seven to eight times in shares during the course of the CSA season. CSA members usually receive two winter squashes for each distribution, except delicata and honeynut, for which four are given out each time.

Post-harvest Handling

Winter squashes are all washed in the brush washer with a SaniDate sanitizing spray. After washing, they are sorted and counted into macro bins. Bins are labeled with the type and number of squashes. When squash is ready to hand out, the number needed for distribution is counted into dark-green bins.

Butternut squashes benefit from a curing period in a warm environment with good air circulation for four weeks to develop sugars. Honeynut and pumpkin also develop full color after two to three weeks of curing. Other squashes do not need to cure and can be given out right after harvest.

Storage

Winter squash and pumpkin are optimally stored at 50°F to 55°F. Macro bins are lidded but no plastic pallet covers go over the dark-green bins.

Depending on quality, winter squash and pumpkin are stored for one to six months or more. Squashes are checked regularly for any that are turning soft. Soft ones are removed immediately to compost.

Squashes are stored in macro bins until distribution.

CROP HANDBOOK: WINTER SQUASH AND PUMPKIN

Family: *Cucurbitaceae*

Jester delicata.

Waltham butternut.

Honeynut.

Delicata JS.

Tiptop acorn.

Cinnamon Girl PMR pie pumpkin.

Standard Operating Procedures (SOPs)

In this section, a series of SOPs cover on-farm operations as well as management of different aspects of CSA production. These SOPs are site-specific to the UK-CSA, and they reference specific locations and on-site practices. The SOPs can be used as a guide for different farms but would require modification in the context of another operation.

To skip directly to a specific SOP section in this document, click on the bolded title below.

Detailed SOPs cover the following greenhouse activities:

Greenhouse Seeding
Greenhouse Vacuum Seeding
Greenhouse Potting Up
Greenhouse Hardening Off

Additional SOPs address the "how-tos" of specific UK-CSA protocols:

Row Covering and Netting
Field Fertigation
Tomato Tying

In addition, several SOPs discuss key management areas:

Greenhouse Management
Irrigation Management
Harvest Management
Packing Shed Management
High Tunnel and Solar Greenhouse Management

1 . SOP: GREENHOUSE SEEDING

Review the checklist every time when working in the greenhouse.

Figure 1.1

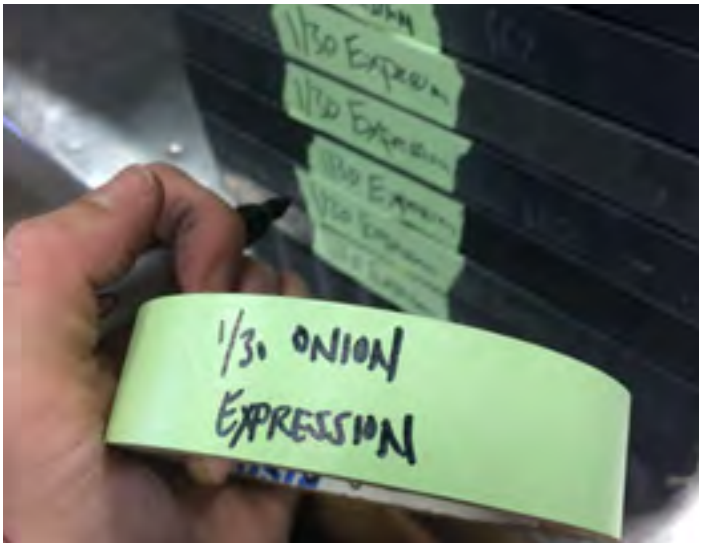


Figure 1.2

Table 1.1

Greenhouse Media Selection	
Germinating flats for herbs, flowers	ProMix
Turmeric, Ginger	ProMix
Select Cucurbits: Summer Squash, Winter Squash, Cantaloupe	ProMix
Microgreens, Shoots	ProMix
Everything else	Vermont Compost

1. Before starting to seed crops into trays, gather supplies:
   - Greenhouse Calendar
   - **Seeds from the seed storage location**
   - **Potting media and mixing bin**
   - **Greenhouse cart**
   - **Clean trays**
   - **Label maker or labeling tape and pencil or Sharpie marker**
   - **Vacuum seeder or hand-seeding tools**
2. Choose trays of the correct size from the clean stack in the greenhouse. Winstrip trays are labeled "ORG" for organic production and have the Winstrip number written on the side. There are four sizes of trays, from smallest to largest cell size: 162, 128, 72, and 50. Consult the Greenhouse Calendar to choose the correct tray size (Figure 1.1).
3. Label all trays prior to filling them. The tape will stick better before hands get wet when mixing the media in the next step. Always label with the seeding date, the crop name, and the variety name. When crops are going into a mixed-use house, designate them with initials or an abbreviation (e.g., "CSA"). Printed labels are preferred. When writing labels by hand, do not use ink pens on the labels, as they fade quickly. Pencil is best, but a black Sharpie marker is also suitable. Place labels on the short end, where they will face out and can be easily seen when they sit on the benches inside the greenhouse(Figure 1.2).
4. Fill the mixing bin with scoops of potting media. Reference the **Greenhouse Media Selection** table (Table 1.1).

   Fill mixing bin three-quarters full, so there is space to move the media around to mix it (Figure 1.3).

Figure 1.3

1 . SOP: GREENHOUSE SEEDING

Figure 1.4

Figure 1.5

Figure 1.6

5. Moisten the media with clean water and thoroughly mix it in. Add a little bit of water at a time until the proper moisture is reached. This step is important to avoid the pitfalls of overly dry media; media not properly moistened will become hydrophobic and repel water (Figure 1.4).

   To test for proper moisture, make a ball with the media. When this ball is dropped from about one foot above the mixing bin, it should readily fall apart on contact (Figure 1.5).

6. To fill trays, sit the tray inside the mixing bin and pile the media on top of the tray. The important part is to pack the media evenly into the trays without over compacting it. To achieve this, shake the trays by picking them up several inches and then dropping them down several times to settle the media. Pile on top a second layer of media, being sure to pay attention to the corners, which are the areas of the tray most likely to get filled unevenly. Once the tray is packed well, brush all excess media back into the mixing bin. Set the filled and smoothed tray aside until ready to dibble (Figure 1.6).

7. Select the dibbler that matches the Winstrip tray size. If seeding squash or melon, skip this step and go straight to Step 9.

   Center dibbler on top of each tray and press down evenly to make indentations in the center of each cell (Figure 1.7).

8. If using the vacuum seeder, see **SOP: Greenhouse Vacuum Seeding.**

Figure 1.7

9. If hand-seeding, select the appropriate seeding tool. If seeding squashes or melons, these seeds are easily dropped individually in the cells by hand. However, the best way to seed larger items is by setting them on top of a tray that is not dibbled and then pressing them down into the cell by hand. This pressure helps create a dibble at the desired depth and also functions to help secure the seed in the tray (Figure 1.8).

   Be sure to only hold a small amount of seed in hand at a time to prevent extra seed from being contaminated with potting media or moisture.

   When hand-seeding smaller items, tools like widgers, scoop spatulas, micro spatulas, or hand sowers are helpful. A micro spatula can also be used to singularly drop seeds held in the scoop spatula (Figure 1.9).

10. Each cell should have one seed. Once the seeds have been deposited into each cell, the tray can be covered with another thin layer of potting media. Place the tray inside the mixing bin again and mound up a top layer of potting media. Lightly press down while smoothing out the surface, brushing the excess back into the bin. Since the tray was dibbled, no seeds should get moved around out of their cells.

11. Place completed trays on a greenhouse cart. Multiple trays may be stacked on one another at an offset. Once the cart is filled, transport trays to their destination and carefully unload, always using two hands. Make sure labels face out on the benches. Always water the trays immediately after placing them in the greenhouse. Be sure to extend the waterer past the edges of each bench for proper coverage (Figures 1.10 and 1.11).

Figure 1.8

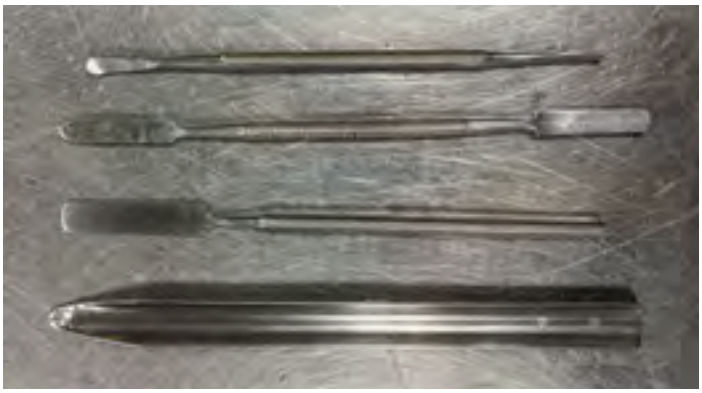


Figure 1.9

Figure 1.10

Figure 1.11

1 . SOP: GREENHOUSE SEEDING

Greenhouse Operations Clean-Up Checklist

- ☐ Do crops need to go on a heating mat? If so, was the heating mat set to the correct temperature?
- ☐ Do crops need to go under the misters in House 2?
- ☐ Were trays watered once they were placed on the greenhouse benches? Are crop labels facing outward?
- ☐ Was the **Greenhouse Calendar** completed with seeding date and seeded amounts?
- ☐ If seed is short or cannot be found, was the CSA manager notified?
- ☐ Was the work surface wiped down after use?
- ☐ Was the floor around the workstation swept? Was the hallway checked, to see if further sweeping was necessary?
- ☐ Were the greenhouse cart and dibbler trays sprayed off with water after use? Was the cart returned to the hallway?
- ☐ Was the floor squeegeed into the head house floor drain after spraying the cart?
- ☐ Was all seed stowed back in the appropriate labeled bins and labeled bags?
- ☐ Was the potting media mixing bin and cart stowed in the hallway?
- ☐ Were the CSA hand tools and **Greenhouse Calendar** returned to the ticket holder and hung in the greenhouse?

2. SOP: GREENHOUSE VACUUM SEEDING

A Berry Precision Seeder is used to vacuum seed several crops, including brassicas, leeks, pelleted lettuce, onions, and spinach.

1. After the trays are filled with potting media, use an appropriately sized dibbler to make indentations in each cell of the tray into which the vacuum seeder will deposit the seeds. Dibblers are metal trays with marbles glued in the pattern of the cells for each tray size (Figure 2.1).

   The dibbler size should match the tray size. For example, on a tray containing 128 cells, each cell measures one-half inch squared. Size labels are written in permanent ink on the side lip of the dibbler (Figure 2.2).

2. Flip the dibbler upside down on top of the tray. Line up the four corners to ensure the dibbler is centered on top. Press down firmly and evenly across the entire backside of the dibbler until it sinks into the tray cells (Figure 2.3).

3. When the dibbler is removed, there will be indentations centered in each cell where the seeds will be deposited (Figure 2.4).

4. Rinse off the dibbler after use before stowing.

5. The Berry Precision Seeder is a polycarbonate box that uses a small vacuum with an attached hose to suction seeds to a seeder plate corresponding to the greenhouse tray. The seeder plates are interchangeable. Similar to the dibbler, each seeder plate is labeled on the outer edge to correspond with a specific tray size. If the seeder plate needs to be changed, begin by unscrewing the four screws located in the four corners of the seeder plate with a Phillips screwdriver (Figure 2.5)

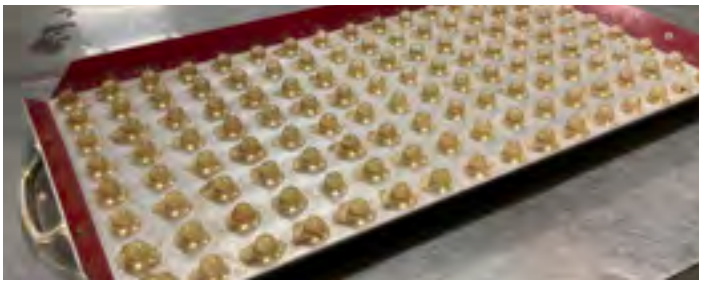


Figure 2.1

Figure 2.2

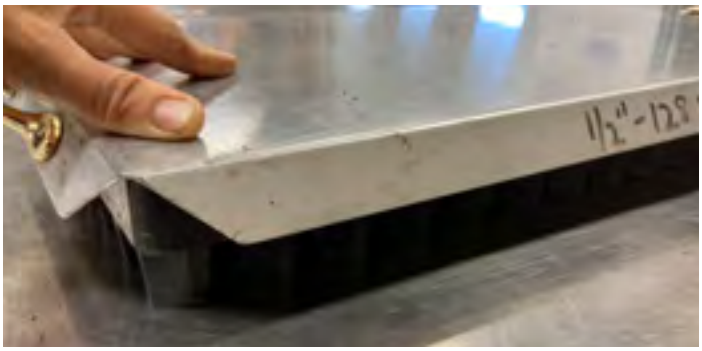


Figure 2.3

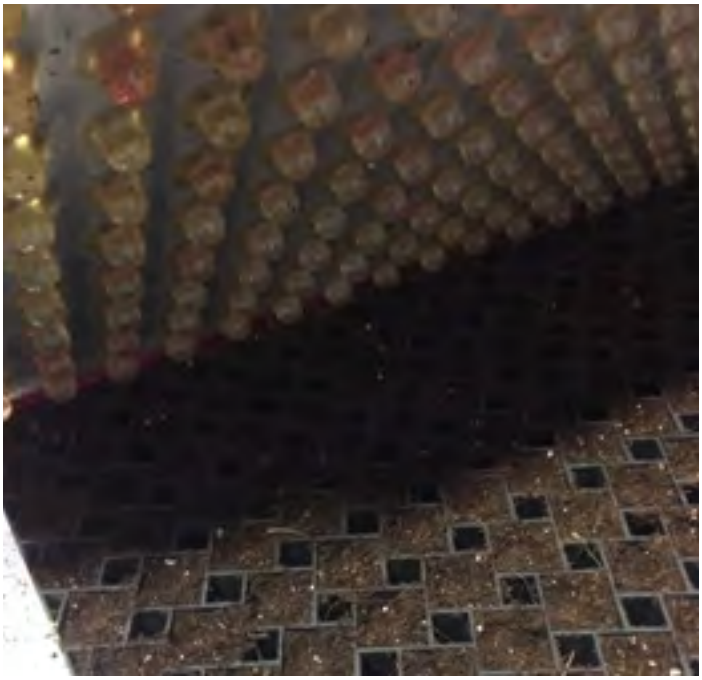


Figure 2.4

Figure 2.5

2. SOP: GREENHOUSE VACUUM SEEDING

Figure 2.6

Figure 2.7

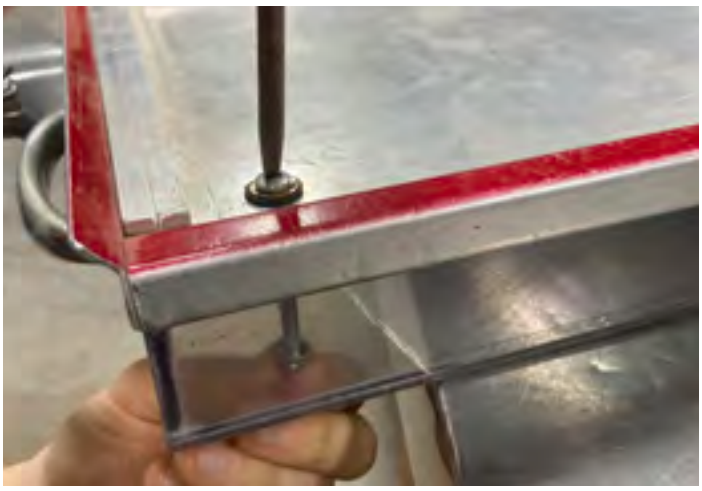


Figure 2.8

6. Remove both the screw and rubber gaskets from the top, and the rubber feet holding the nut on the bottom of the polycarbonate box. These screws, gaskets, feet, and nuts should be set aside, as they will be reinserted to attach the new seeder plate (Figure 2.6).
7. Each seeder plate has rubber strips along the backside in the shape of the plexi box (Figure 2.7).

   When placing the new seeder plate, line up all rubber strips with the top edges of the polycarbonate box. These strips are important for proper suction. If any strips are peeling or degraded, replace them with new adhesive-backed rubber strips. Be sure the seed channel along one of the long edges of the seeder plate is at the bottom, closest to the edge of the worktable.
8. Reinstall the screws, gaskets, rubber feet, and nuts in each of the four corners. Tighten with the Phillips screwdriver until snug. Hold the rubber feet in place at the bottom while tightening the screws from the top (Figure 2.8).
9. The vacuum seeder is powered by a simple, small vacuum or shop vac. There are two hose openings in the polycarbonate box, on the left and right sides. Insert the vacuum hose end into either side and push the lever out to the open position (Figure 2.9).

   On the opposite side, push the lever in to close the hose opening. The levers control the suction, so for maximum suction, the hose end stays open and the opposite side is closed.

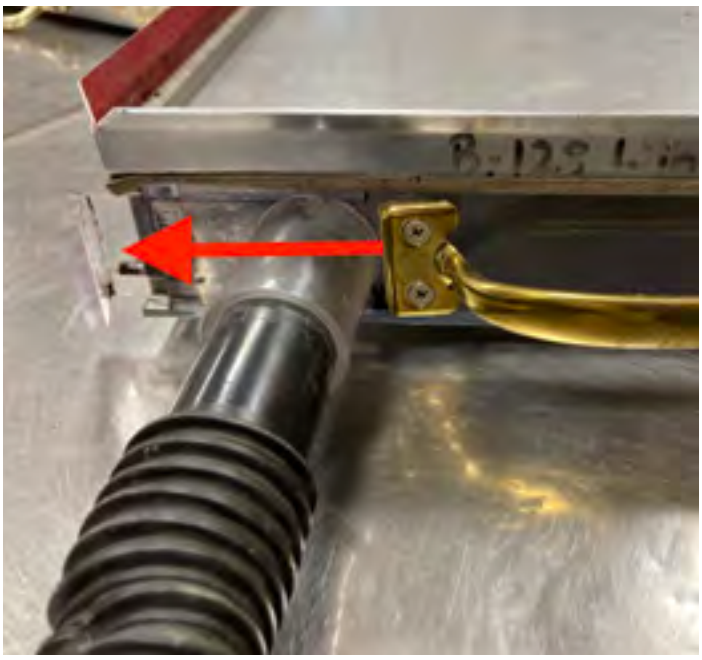


Figure 2.9

2. SOP: GREENHOUSE VACUUM SEEDING

10. When it is time to seed, pour some seed onto the surface of the vacuum seeder plate (Figure 2.10).
11. Turn the vacuum on and make sure the suction is working. If the seeds do not stay on the holes, there is inadequate suction. Adjust the levers, if necessary. If the levers are too loose and not staying in position, tighten the plastic screw on the side next to the lever with a flathead screwdriver (Figure 2.11).

    Individual holes may need cleaning if they get potting media or other debris stuck in them. The orifice cleaner is a small handheld tool with metal rods of different diameters that can be inserted into holes to clear any obstructions (Figure 2.12).
12. Gently shake the vacuum seeder box from side to side to move the seeds around until each hole contains a single seed. If multiple seeds stick on the holes, lightly tap the back of the box against the worktable or manually dislodge the extra seeds from the holes (Figure 2.13).

Figure 2.10

Figure 2.11

Figure 2.12

Figure 2.13

2. SOP: GREENHOUSE VACUUM SEEDING

13. Gently tilt the box forward at a 45-degree angle. Any loose, extra seed will then roll down into the seed channel at the bottom of the seeder plate. This seed channel holds extra seed and keeps it from being lost (Figure 2.14).

    Note: If the seed channel is overflowing, too much seed was dropped on the seeder plate in Step 10.

14. Now it is time to line the vacuum seeder up with the tray. Tilt the vacuum seeder perpendicular to the tray and slowly lower it facedown on top of the tray. There are two ledges on the seeder tray surface. These ledges should hold the edges of the tray snug so it does not slide around. Be sure the machine is settled over the tray edges. If the seeder can be pushed side to side at all, the seeder is not set properly (Figure 2.15 and 2.16).

15. Push the seeder forward on the tray until it hits the tray's edge. When no more movement is possible, it is snugly placed on top and should be perfectly aligned.

16. Next, the seed is dropped into the tray. Simply release the suction by closing the hose lever on the side with the vacuum and opening the lever on the opposite, empty side. Sometimes a residual suction will momentarily continue to hold the seed in place. Gently knock the polycarbonate bottom of the seeder, facing up, to ensure the suction seal is broken.

17. When lifting the vacuum seeder off the tray, always raise it from the top, the edge closest to oneself, upwards. This ensures the extra seed captured in the seed channel on the bottom stays in place.

18. Check the cells of the tray. Make sure the seeds have fallen into the dibbled areas. If a hole or two is missing a seed, quickly hand drop a seed into the empty cells. If the seed is not in the dibbled center, then it was not lined up properly. Finally, cover the seeds with potting media.

19. Once all of the trays of a certain crop variety have been vacuum seeded, tilt the vacuum seeder so that all the seeds fall into a corner of the seeder plate. Tap the extra seeds back into their seed container (Figure 2.17).

Figure 2.14

Figure 2.16

Figure 2.15

Figure 2.17

3. SOP: GREENHOUSE POTTING UP

"Potting up" or "Potting on" is the process of moving a plant from a smaller cell to a larger cell. This process is important for crops that benefit from being in the greenhouse for a longer period.

1. Potting up is only done with certain crops. Consult the **Greenhouse Potting-Up Selection** table for reference (Table 3.1).
2. Start by removing individual plant cells from the tray. If multiple plants occupy one cell, gently pull them apart, holding onto the leaves if possible and not the stems, to separate their roots. If there is only one plant in the cell, loosen the root. If the plant is not rootbound, then little root separation will be required.
3. Fill a new tray with potting media. Place a new label on the tray with the potting-up date.
4. Lay the plant and its roots on top of the new cell. Place a micro spatula or spoon spatula tool in the middle of the root zone. Use the tool to gently press the roots down into the cell. A second push may be necessary to get all the roots buried in the tray. All roots must be below the surface (Figure 3.1).
5. This process will get the plant in the cell, but it will leave a small indentation on the surface (Figure 3.2). When the tray has been completely filled, add potting media into the gaps created at the surface. Going row by row, drop in small handfuls of media. Press it down to help secure the plant and shake off any excess.

Figure 3.1

Table 3.1

Greenhouse Potting-Up Selection	
162 to 50 cell	Eggplant, Peppers, Tomatoes
128 to 72 cell	Celery, Leeks, Herbs, Flowers

Figure 3.2

4. SOP: GREENHOUSE HARDENING OFF

Hardening off is the process of gradually acclimating crops from their greenhouse environment to the elements outdoors, prior to planting, in order to reduce transplant shock.

Figure 4.1

1. Prior to hardening off, check plants for proper root-ball development. The root should hold the potting media together so that the media does not separate from the plant roots (Figure 4.1).
2. Consult the **Hardening Off Minimum Air Temperatures** table for the scheduled crops (Table 4.1). If crops are hardened off too early, the small plants may suffer cold damage.
3. Hardening off is done gradually, so that seedlings become accustomed to strong sunlight, cool nights, wind, and less frequent watering. The goal is to harden crops off over seven to 10 days.

   On a mild day, start with two to three hours of sun in a sheltered location. Use a wagon or a cart to bring plants outside and then move them back inside when needed (Figure 4.2).
4. Protect seedlings from strong sun, wind, hard rain, and cool temperatures. A hardening off area bordered on two sides by greenhouses and other buildings provides a windbreak and some shading (Figure 4.3).

Table 4.1

Hardening Off Minimum Air Temperatures		
Hardy	40°F	Broccoli, Brussels Sprouts, Cabbage, Kohlrabi, Leeks, Onions, Parsley
Half-Hardy	45°F	Celery, Endive, Lettuce, Napa Cabbage
Tender	50°F	Squash, Pumpkin, Sweet Corn
Tender	60°F	Cantaloupe, Cucumber
Tender	65°F	Basil, Eggplant, Peppers, Tomatoes

Figure 4.2

Figure 4.3

5. Increase exposure to sunlight a few hours at a time and gradually reduce frequency of watering. Be mindful to not let the seedlings wilt. Avoid fertilizing.
6. Consult the **Direct Seeding and Transplant Soil Temperature Recommendations** chart for the relative hardiness of various crops and recommended soil temperature prior to planting (Table 4.2).

   Onions and brassicas are hardy and can take temperatures in the 40s. After they are well hardened off, light frosts will not hurt them. Warm-season crops such as eggplants, melons, and cucumber prefer warm nights, with temperatures of at least 60 degrees Fahrenheit. They cannot withstand below-freezing temperatures or frosts, even after hardening off.
7. Gradually increase exposure to outdoor conditions over four to seven days until crops can stay outdoors in the sheltered hardening off area overnight.
8. Keep an eye on the weather and the low temperature predictions for overnight. If temperatures below the crop's minimum air temperature are forecast, bring the plants indoors or cover them with a row cover for protection.

   Row covers are also essential at the outset if hardening off crops that are susceptible to flea beetles, like eggplant. Trays of plants are covered directly on the hardening bench or wagon (Figure 4.4).
9. When seedlings are ready to plant, use a little bit of fertilizer to get transplants growing again and avoid transplant shock. Be sure to water plants after planting (Figure 4.5).

Table 4.2

Direct Seeding and Transplant Soil Temperature Recommendations		
Plant BEFORE frost free date	Soil temp 45°F or above	Beets, Broccoli, Carrots, Lettuce, Onions, Peas, Spinach, Turnips
	Soil temp 50°F or above	Cabbage, Cauliflower, Leeks, Radish, Swiss Chard
Plant AFTER danger of frost	Soil temp 60°F or above	Beans
	Soil temp 65°F or above	Untreated Corn seed
	Soil temp 70°F or above	Cucumbers, Melons, Okra, Pumpkins, Squash, Watermelons

Figure 4.4

Figure 4.5

5. SOP: ROW COVERING AND NETTING

Row covers are used for thermal buffering, wind protection, and pest exclusion. Netting is only used for pest exclusion.

Figure 5.1

Figure 5.2

1. Two people work together to install hoops, with one walking on each side of the bed. One person holds a stack of hoops and installs one end of each hoop in the soil on one side, while the second person helps to grab the other hoop end and push it into the soil on the opposite side. (Figure 5.1).
2. Single hoops should be spaced apart every five feet in row. Hoops can also be doubled up and used in a crisscross fashion. This provides more stability and may allow for greater spacing between the sections, but it will require more hoops. At UK-CSA, we start and end every bed with two crisscrossed hoops.

   If hooping and covering multiple beds side by side, stagger the hoop spacing in the adjacent beds for greater stability with larger covers.
3. Using two to three people, have one person drive the forklift carrying the pallet of pavers in the drive row next to the field. The second worker wears work gloves and unloads the pavers from the pallet as the forklift moves down the row. They drop one paver every four to five feet and toss a paver to the other side, or to the third person, standing inside the field closest to the beds to be covered (Figure 5.2).

Tip: By moving the forklift backwards down the drive row, workers can always face the driver, and danger of moving in the path of the tractor is minimized.

4. Once the pavers are dropped, the row cover can be pulled out the length of the bed. If the row cover is in a macro bin, this can also be carried by a forklift and driven alongside the field. The workers can pull the cover or netting out of the macro bin. If the netting is daisy chained, it should also be unchained at this step and pulled down the length of the field (Figure 5.3).

Figure 5.3

Figure 5.4

Figure 5.5

5. Pull the cover over the crops until it is loosely hanging across the entire section to be covered (Figure 5.4).
6. Covering is best done with four people who work in pairs. Each pair works on one side of the bed being covered. The key is for the pairs to work together and not get ahead of one another.

   Each pair will have one person as the netting positioner and one person as the paver placer. The positioner stays in front of the paver placer. The positioner's job is to pull the net firmly to the ground and away from the placer by gently tugging the cover or net at the bottom edge. The partner then sets the paver on top of the cover or net edge. It is placed close to the hoop and on the net fully, if possible, for maximum hold (Figure 5.5).

   Roll or fold any excess on the edges in on itself, until the net is tight across the hoops (Figure 5.6).

   Once the paver is placed, both workers move down five feet to the next paver and repeat the action. Pairs on each side of the netted area should stay close to one another, so that the cover or net stays smooth and tight against the top of the hoops. If there is excessive slack, the covers will ripple in the wind. This is a sign that the cover is not pulled down tightly enough.
7. Once the long sides have been weighted, be sure the two ends are also closed off and weighted to finish.

Figure 5.6

6. SOP: FIELD FERTIGATION

Only crops reaching maturity beyond 56 days are fertigated.

1. To prepare for fertigation, first weigh out the calculated amount of Allganic Nitrogen Plus 15–0–2 into a clean, empty five-gallon bucket. (Figure 6.1).
2. Use a broom handle or stick to mix water into the fertilizer bucket to create a slurry (Figure 6.2).

   Pour slurry into tank of fertigation injector.
3. Add approximately 10-15 gallons of additional water to the tank in order to increase the quantity of water and extend the time of fertigation (Figure 6.3).
4. After the irrigation water has run in the field for about two-thirds of the entire time desired to irrigate, begin fertigation. Drive the fertigation injector, connected to the ATV, out to the field (Figure 6.4).
5. Halt irrigation supply to the field to be fertigated by turning off the ball valve on the header manifold. Remove the header coupler from the manifold and insert the fertigator tee.

Figure 6.1

Figure 6.2

Figure 6.3

Figure 6.4

6. Once the fertigator tee is inserted next to the start of the header line, turn the ball valve on the header manifold back to the open position. The ball valve may need to be partially closed to reduce water flow for the fertigation pump to inject properly. (Figure 6.5).
7. Turn the fertigator switch to "on" and open up the valves on the pump (Figure 6.6).
8. If there is too much pressure, the tank will not decrease. If the tank is being emptied rapidly, partially close the water valve to slow down the rate of injection. Ideal pump pressure is around 15 psi, which is more than the drip line pressure of 12 psi to ensure proper injection. Check to make sure the tank is steadily decreasing (Figure 6.7).
9. Shut off the pump switch before the tank empties entirely to avoid the need to prime the pump on the next fertigation. A gurgling noise will be the cue to stop. A small amount of water will still be in the tank.
10. After completing fertigation, turn the manifold off again to remove the fertigation tee. Resume irrigating the field to flush the lines with clean water and complete the final third of the desired irrigation duration (Figure 6.8).

Figure 6.5

Figure 6.6

Figure 6.7

Figure 6.8

7. SOP: TOMATO TYING

Figure 7.1

Figure 7.2

1. Start with a box of Gro-Tie twine attached to one's belt. If a worker is not wearing a belt, a scrap of drip irrigation line can be used as a belt to hold the box at one's waist (Figure 7.1).

   Run the end of the twine through two holes drilled into opposite ends of a wooden handle or broomstick. The twine is pulled through the first hole at the top of the handle, and then pulled down the length of the handle and pushed through the second exit hole at the bottom of the handle. Pull one to two feet of twine out from the bottom hole.

2. Secure the twine to the bottom of the first T-post with a simple overhand knot, about four inches above the bed top. Each additional tie starts about four to five inches above the preceding one (Figure 7.2).

   Next, the worker begins the Florida weave. The Florida weave is a figure-eight pattern of tying tomatoes. Each worker will walk the entire tomato bed in two passes.

   Note: The photos show the second pass, which completes the figure eight.

3. During the first pass, the worker uses the broomstick to run the twine on the back side, outside of the first tomato plant (Figure 7.3).

Figure 7.3

7. SOP: TOMATO TYING

4. The worker then pulls the twine across the middle and to the front of the second tomato plant (Figure 7.4).
5. Circle the broomstick around the second T-post, lifting the twine by hand over the top of the post (Figure 7.5).

   The twine should make an S pattern around the two tomato plants. The twine should be kept taut at all times.
6. On the next section, the pattern is mirrored. The twine comes off the front side of the second T-post and will stay in front of the third tomato plant (Figure 7.6).

   Pull the twine across the middle, and around the back side of the fourth tomato plant. Circle the third T-post once. From there, a mirrored S pattern is created around the next two tomato plants.

Figure 7.4

Figure 7.5

Figure 7.6

7. Repeat this process until the end of the row is reached. At the end of the row, wrap the twine several times around the end T-post.
8. The worker now walks around the bed to the other side and completes the second pass in the opposite direction. Following the same pattern, the twine will now make a complementary S pattern around each set of two tomato plants to complete the figure-eight design.
9. At the completion of each figure eight, there should be one tomato plant held by twine on front and on back, which represents the top of the figure eight, and the second tomato plant should likewise be held by twine on front and on back for the bottom of the figure eight. Each plant should be contained in its own pocket, and the crossover in the middle should keep each plant from touching another. In addition, the height of the twine should be level along the length of the row. There should be no vertical gaps of space between the two twine passes (Figure 7.7).
10. If the twine did not capture the plant in the first attempt, workers should bend down to fix plants or have a helper go back through and situate plants in between the twine. It is better to keep the twine taut on the first passes and fix plants afterward rather than leave the string too loose at the start.

    Note: If the T-posts are not installed in-row with the plants, the twine will not capture the plants and more tucking will be required (*Figure 7.8*).
11. Each half-bed is ended with several wraps around the last T-post. The twine is knotted, and then the end is cut with a pocketknife.
12. Additional ties are made weekly, so each row of indeterminate tomatoes may be tied five or six times in a season, based on plant height.

    The ties after the initial strand omit the crossover to make the figure eight. Instead, twine is carried only on the front and back side of plants from T-post to T-post, sandwiching both plants in a pocket of twine. Twine is wrapped around each T-post once before running the next line. All lines of twine are kept level as before, spaced four to five inches above the prior tie.

    To view videos of the Florida weave technique, click on the following links:

    Video 1: Florida weave

    Video 2: Florida weave

Figure 7.7

Figure 7.8

8. SOP: GREENHOUSE MANAGEMENT

The greenhouse manager monitors and stays aware of the activities of the greenhouse, including seeding, potting up, fertigating, scouting, hardening/moving plants around if needed, and in general, making sure transplants are ready for transplanting.

Schedule

The greenhouse manager's tasks should be completed at least once during the week, but may be necessary every day of the week, or at least two or three days per week, at peak times.

Scouting

The greenhouse manager inspects UK-CSA plants held inside the certified organic (ORG) houses: ORG House 2 and ORG CSA House. Scouting activities include the following responsibilities:

- Checking plants for poor germination
- Checking trays for doubling in cells and thinning
- Inspecting for insect issues (e.g., aphids, fungus gnats, white flies, and flea beetles)
- Inspecting for fungal issues (e.g., damping off)
- Checking for plants ready to be hardened off
- Checking for signs of plants in need of fertigation (e.g., age, yellowing, and size)
- Checking seeding schedule for the current week's seeding needs
- Checking for potting-up readiness
- Checking for old plants and trays to be cleaned out
- Checking inventories (e.g., clean trays, potting media, seeds, and fertilizer). Inventory checks are made in December/January in preparation for the next year and monthly, or as needed during seeding. Any material shortages are reported to the CSA manager.

Germination

Count seedlings in trays and compare to number needed for field on the Greenhouse Calendar. Seed more as soon as possible, if necessary.

Thinning

If there is more than one plant per cell, additional plants are pinched off as early as possible. If cell germination is spotty or uneven, any additional plants in a single cell are pulled out and moved to an empty cell.

Insect Issues

Look under leaves and at the growth points for insect pests. Some insects can be excluded (e.g., flea beetles) by using row covers over susceptible crops, such as eggplant, when they are moved outside.

Depending on how heavy the infestation appears, insects are picked off or sprayed off with a stream of water, or the plants are treated with a pesticide, using an atomist electric sprayer.

Fungal Issues

Damping off often occurs due to overwatering. Watering is done by the facilities manager or arranged by the farm superintendent on holidays and weekends. Plants of different sizes have different watering requirements. If the whole tray has uneven germination, this will cause some cells to dry out quicker and others to stay moist for longer.

If plants appear slow growing or stunted, pull plugs out of the trays and inspect the roots. Lack of proper root development is also evidence of fungal issues. Reseeding may be necessary if substantial fungal issues are present. Note the crop and variety that is incurring fungal problems and notify the CSA manager.

Hardening Off

The Greenhouse Calendar includes a hardening-off schedule. Check plants for good root-ball development as an indicator of plant readiness. Hardening off of plants prepares sheltered seedlings for being in an open, uncontrolled environment. See SOP: Hardening Off Crops for more information.

Fertigation

Most plants do not need to be fertigated often. For the amount of time that most plants are in the trays, there is enough fertility in the potting media, and no additional fertility is needed until the time of transplanting.

Most plants grown in media with added fertilizer or in compost-based media will require fertigation or potting up with new media four to six weeks after emergence. Any weekly fertigation events are stopped one week before hardening off. Final fertigation is done immediately before planting. Daily rate is 15-30 ppm of nitrogen. The weekly rate is 200-300 ppm of nitrogen. Basil can be used as an indicator crop for fertigation needs, as it shows nitrogen deficiencies clearly.

Seeding

Check the Greenhouse Calendar for the list of crops that need to be seeded that week. Make sure the CSA manager is

aware of what needs to be done that week, so that it gets put on the task list. Take note of how many trays will need to be seeded so the appropriate number of people are assigned to the job. If it is less than 10 to 12 trays, only one person is needed. Group all weekly greenhouse seedings together on the same day to save on time required for set up and clean up. See **SOP: Greenhouse Seeding**, **SOP: Greenhouse Vacuum Seeding** for more information.

Potting Up

The potting-up dates are estimated on the Greenhouse Calendar. Make sure there are enough clean trays for the task and that crops are potted up in a timely manner. See **SOP: Greenhouse Potting Up** for more information.

Cleaning

After transplanting, the leftover crops are brought back to the hardening-off benches behind the greenhouse to be watered. Typically, these plants are held onto for at least one week for possible use as replanting stock where field transplants may have died from transplant shock. After one week, the plants are composted. Remove the labels from the trays and bring the empty, dirty trays to the packing shed for washing on the rinse conveyor. Dirty trays that were taken to the field should not be brought back to the greenhouse until cleaned, as they pose a pathogen risk.

In the case of some transplants that are sold, the plants are held onto longer in order to be sold at future farm stands. These crops include flowers, herbs, tomatoes, and peppers.

Inventory

Be aware of inventory when seeding and checking on crops. If fertilizer or potting media (PRO-MIX or Vermont Compost) becomes low, notify the CSA manager.

Other Notes

Heat mats are available for general use. Check with the facilities manager for their availability. Crops that benefit from heat mats include peppers (80°F), early tomatoes (75°F), and some flowers (70°F to 85°F, depending on variety). Once a tray reaches 75-80 percent germination, it should be removed from the heat mat.

Crops that belong under misters include herbs and flowers for germination and any brassica or lettuce crops seeded in June or July during the heat of summer for cooling. Check with the facilities manager for space under the misters in House 2 and any adjustments needed for misting intervals, if the trays are getting inadequate or excessive watering.

As plants grow, some will grow taller and faster than others. If a slower-growing, smaller plant is placed next to a faster-growing, bigger plant, the bigger plant will shade or crowd the smaller one out. If an entire tray of smaller plants is set next to larger plants, the entire tray may suffer from inadequate watering as well. Move the smaller tray where the larger plants cannot overshadow it.

Similarly, keep newly seeded trays grouped together so older plants do not interfere.

When plants get larger, keep some space in between the trays so transplants do not get intertwined. Spaces between trays will make watering coverage more even and allow for the best possible airflow to decrease chances of disease.

Place trays strategically on the greenhouse benches. All trays are first placed on the same side of the house, and when a full side bench is filled, newly seeded plants will be moved to the next bench. Grouping trays together helps the waterer to work efficiently and maintain even watering.

9. SOP: IRRIGATION MANAGEMENT

Irrigation is managed to ensure that crops get the proper amounts of water at the right time to reduce crop stress and optimize crop yield. The soil type at UK-CSA is a Maury silt loam. This soil has a water-holding capacity of 2.5 inches per foot, or 0.2 inches of water per inch of soil[1]. The drip tape used is Toro Aqua-Traxx Premium drip tape, 8 mil thickness, with six-inch emitter spacing. It has a flow rate of 0.67 gallons per minute (GPM) at 8 psi, or 0.82 GPM at 12 psi[2].

In order to provide crops with a base level of one inch of water a week, it will require 3.8 hours of irrigation per bed with one drip line per bed or two hours with two drip lines per bed at 0.82 GPM. Rainfall and evapotranspiration (ET) must also be factored in for day-to-day irrigation management.

While many crops can withstand 40-60 percent soil moisture depletion before irrigation, some crops are more sensitive and can only withstand 20-25 percent depletion. Sensitive crops include celery, onions, peppers, spinach, and strawberries[3]. Therefore, the maximum management allowed depletion (MAD) of moisture before an irrigation event is 20 percent when all crops are managed on the same irrigation schedule. For silt loam soils, this is 0.5 inches of the maximum 2.5-inch water-holding capacity lost. When using a soil moisture tension sensor, like Irrometer Watermark sensors or Irrometer SR tensiometers, the 20 percent MAD occurs at 36 centibars for loams[4]. Any value higher than 36 centibars is the threshold for irrigation.

Figure 9.1 Tensiometer.

Figure 9.2 Watermark sensors.

Irrigation Event Scheduling and Duration

To determine the next irrigation event, several steps are necessary:

1. Consult the evapotranspiration rates at http://wwwag-wx.ca.uky.edu/ky/agmodels.php. Click on "Irrigation Manager" on the left side bar and select your county and dates to find the calculated reference evapotranspiration value (ETo).
2. Multiply the ETo reference value online by the crop coefficient (Kc) in Table 9.1 to get the specific crop evapotranspiration amount (ETc). Several ETc values may be added for a weekly total.
3. Subtract the total ETc value from a field capacity of 2.5 inches.
4. Add back the value for rainfall accumulation for the week for bare-ground beds, but only add rainfall accumulation in excess of one inch for plasticulture beds.
5. The result is the plant available water (PAW) amount for that week.
    - Values above 2.5 inches indicate no irrigation is necessary, as the field is at capacity.
    - Values below 2.5 inches indicate moisture depletion. When the value dips below two inches, this is 20 percent or more depletion, and irrigation should be initiated.
6. Determine duration of irrigation event based on water requirements, pressure, and number of drip lines per bed using Table 9.2.
7. If the initial field capacity is unknown, use Watermark sensors or tensiometers installed at depths of six to 12 inches to establish reference points (Figures 9.1 and 9.2). The Watermark sensors will provide values in kPa or centibars; 36 centibars for loamy soils indicates 80 percent AW, which is the 20 percent depletion threshold. If the centibar reading is 36, then soils need 0.5 inches of water to regain field capacity of 2.5 inches.

9. SOP: IRRIGATION MANAGEMENT

Table 9.1 Crop coefficients[5].

Crop	*Kc Initial Growth*	*Kc Middle Growth*	*Kc Ending Growth*
Beans	0.5	1.05	0.9
Beets	0.5	1.05	0.95
Broccoli	0.7	1.05	0.95
Cabbage	0.7	1.05	0.95
Carrots	0.7	1.05	0.95
Cauliflower	0.7	1.05	0.95
Celery	0.7	1.05	0.95
Corn	0.3	1.15	0.4
Cucumber	0.6	1	0.75
Green Onions	0.7	1.05	0.95
Lettuce	0.7	1	0.95
Onions	0.7	1.05	0.95
Peas	0.5	1.15	1.1
Peppers	0.7	1.05	0.85
Potato	0.5	1.15	0.75
Pumpkin	0.5	1	0.8
Raspberries	0.4	1.2	0.75
Spinach	0.7	1.05	0.95
Squash	0.5	0.95	0.75
Strawberries	0.4	1.05	0.7
Sweet Corn	0.3	1.15	0.4
Sweet Potato	0.5	1.05	0.95
Tomato	0.7	1.05	0.8
Watermelon	0.4	1	0.75

Kc = Crop Coefficient

Table 9.2 Irrigation rates.

One line of drip tape per bed	
PSI	Rate (inches water/hour)
4	0.13
5	0.14
6	0.16
7	0.17
8	0.18
9	0.19
10	0.2
11	0.21
12	0.22
13	0.23
14	0.24
15	0.25

Two lines of drip tape per bed	
PSI	Rate (inches water/hour)
4	0.26
5	0.29
6	0.32
7	0.34
8	0.37
9	0.39
10	0.41
11	0.43
12	0.45
13	0.46
14	0.48
15	0.5

Example:_Newly transplanted broccoli plants are irrigated to reach field capacity at time of planting. That week there is a slight rainfall of 0.08 inches. The ET for the past seven days totals 0.91.

Broccoli crop coefficient (Kc) for initial growth is 0.7, therefore 0.91 x 0.7 = 0.64 ET.

The field capacity of 2.5 inches - 0.64 ET = 1.86 inches
1.86 inches + 0.08 inches rainfall = 1.94 inches

Since 0.56 inches of water lost is greater than the 0.5-inch MAD threshold, irrigation is initiated. With field lines at 12 PSI, 0.45 inches of water is applied in one hour on bare-ground, double drip tape beds. Therefore, one hour and 15 minutes of irrigation is required for broccoli.

Duration of each irrigation event depends not only on the plant available water (PAW) but also on psi of the water source, number of drip lines per bed, and maximum number of drip lines that can be supplying irrigation water without a decrease in source pressure. At the UK-CSA system, plastic beds have a single line of drip tape, while bare-ground beds have double lines of drip tape. The psi of individual drip lines can be checked by connecting a pressure gauge to the end of the drip tape line in the field furthest from the header manifold, once the lines have been filled and have good turgor pressure.

Be sure that the scheduled irrigation event does not exceed the soil's capacity to absorb it. For a silt loam, the infiltration rate is 0.25 to 0.40 inches of water per hour[6]. As a result, shorter irrigation events may be needed to reduce water loss.

9. SOP: IRRIGATION MANAGEMENT

At UK-CSA, the main hydrant, after going through a pressure reducer to 35 psi, outputs 78 GPM. With drip tape capable of 0.82 GPM at a maximum of 12 psi, this allows for 9,512 feet of drip tape to be used to maintain pressure, or 31 total 300-foot drip lines in the main fields at one time. Given friction loss and reduction to 50 GPM through two-inch supply lines, 6,097 feet of drip tape, or 20 lines 300 feet long, is a more accurate estimated capacity without significant drop in pressure.

Drip tape is 85 to 95 percent efficient above ground and 95 percent or more efficient subsurface[7]. Therefore, the irrigation rates in Table 9.2 have compensated for this loss of application efficiency, using the lower level of efficiency of 0.85 for an adequate buffer amount. For more than two lines of drip tape on a bed, simply add onto the two drip-line rate the rate for one drip line for each additional line used.

Irrigation Protocols Modified for Specific Circumstances

- Irrigation should occur immediately after direct seeding. Irrigate to apply at least 0.5 to 0.75 inches of water at time of seeding, regardless of field capacity. With subsurface drip lines, it is ideal to irrigate until the wetting pattern is visible on the surface of the soil, which may take more than a 0.75-inch application for water to reach the soil surface.
- If temperatures are cooler than the optimal seeded crop germination range, irrigate for a minimum of 0.75 inches to one inch instead, to keep the soil moist[8,9].
- After this initial soaking, lower rates of irrigation of 0.2 to 0.3 inches at more frequent intervals help to maintain moisture on the soil surface, prevent drying out and crusting, and hasten seedling emergence. Once seeds germinate, follow normal protocols.
- Some crops will require drip tape to be laid on top of the bed to prevent soil surface crusting. Carrots in particular are irrigated on top of the bed if no rainfall is in the forecast, or seeding timing should be adjusted in order to take advantage of a forecasted rain.
- Irrigate immediately after transplanting. Irrigate to apply at least 0.5 to 0.75 inches at time of transplanting[8].
- Irrigate after plastic mulch installation for setting up the wetting boundaries in preparation for planting. The initial plastic mulch bed irrigation should be seven to 10 days prior to transplanting into the bed.
- Increasing the MAD threshold for irrigation (thereby reducing overall irrigation) during early vegetative growth may aid in deeper root development and reduce leaching risk[11].

Field Checks

- Fields and lines need to be checked during the first irrigation to ensure proper functioning and pressure. After confirming proper supply at setup, they should be checked intermittently for the rest of the season. Occasionally, mechanical or animal tears occur in the lines, which are repaired with drip tape loc couplings, or "splicers." Team members who hear or see a leak should fix it, if possible, or alert the irrigation manager.
- Field moisture may be checked by feel using a soil probe at six-inch and 12-inch depths. Silt loam soils will form a ball readily and feel slick on the skin, adhering to one's fingers slightly when under pressure at 50 to 75 percent PAW, and at field capacity, the soil will form a ball easily and will ribbon readily to a one-inch length without breaking when pressure is applied to the soil to push it between thumb and forefinger. Learning the feel of the soil at different water capacities is an effective check on irrigation management decisions.

Tools for Irrigation Management

Irrigation management involves a suite of tools and materials for setup, maintenance, and troubleshooting (Figure 9.3). A five-gallon bucket outfitted with a bucket organizer can hold most of the necessary items:

- Channellock pliers to aid in turning water on or off if ball valves break or are broken
- Punch tool for installing new emitters in header lines
- Drip tape mini valve offtakes, or "emitters," for replacing broken ones
- Splicers for fixing leaks
- Utility knife for making straight cuts on layflat
- Hose clamps for tightening seal of layflat
- Nut driver for tightening hose clamps
- Male and female 1.5-inch and two-inch couplers for replacing any header or supply line connections
- Barbed straight couplings, both 1.5 inches and two inches in diameter, for repairing any supply- or header-line tears
- Scrap drip tape for capping ends of lines
- Pressure gauge to check end of drip lines
- Tubing for adjusting alignment of header-line emitter holes with the beds
- Watermark sensor meter for checking soil moisture tension (Figure 9.4)
- Soil probe for testing soil at six-inch and 12-inch depths by feel (Figure 9.5)

9. SOP: IRRIGATION MANAGEMENT

Figure 9.3 Irrigation supplies and tools.

Figure 9.4 Watermark sensor meter.

Figure 9.5 Soil probe.

10. SOP: HARVEST MANAGEMENT

Figure 10.1 Portable hand-washing station is loaded on the wagon for washing hands in the field.

Figure 10.2 Harvest tote.

The harvest manager is tasked with determining crop readiness for harvest; training and overseeing staff on correct harvest procedures for each crop; keeping crops moving to the pack shed for post-harvest handling; and dividing the workforce efficiently between tasks.

Food Safety Protocols

Be sure all workers wash hands with soap and water prior to harvest. Workers are responsible for choosing the most appropriate harvest clothing (e.g., boots, raingear, hats, or sunglasses) in advance, and they are also responsible for bringing their own water bottles to the field. Long sleeves are recommended for squash harvest, and gloves are recommended for harvesting tomatoes and sweet potatoes.

Materials

The harvest manager ensures all the necessary supplies are loaded on the harvest wagon and brought to the field with the workers. Materials to bring include the following items:

- Harvest Log and pens
- Row-feet wheel
- Scale
- Harvest bins, and one extra bin per worker for use as in-field "drag bin"
- Macro bins, if needed
- Portable hand-washing station with filled water dispenser, soap, and paper towels (Figure 10.1)
- Extra nitrile gloves
- Tote with sanitized tools, as shown in Figures 10.2 and 10.3, and knife sheaths (e.g., lettuce field knives, serrated knives, pruners, loppers, hedge shears, and tobacco knives)
- Rubber bands (small or large) or twist ties, and waist aprons to hold bands
- Bicycle for bathroom breaks
- Quick-cut Greens Harvester, drill, and charged drill batteries (for direct-seeded greens)

Figure 10.3 Harvest tools.

10. SOP: HARVEST MANAGEMENT

All tools are sharpened with the Work Sharp tool-and-knife sharpener and then sanitized with a 10 percent bleach solution prior to use.

Field Setup

Depending on the crop, either the harvest wagon or harvest conveyor will be used and taken to the field (Figures 10.4 and 10.5). If using the harvest conveyor, it must be connected to a tractor with hydraulics (Kubota 5030 or Kubota 9540). If using the harvest wagon, it can be connected to a truck with a hitch drawbar or a tractor with a hitch drawbar.

Crops that are best harvested with the conveyor include broccoli, cabbage, cauliflower, melons, and winter squash. Some crops, including peppers, summer squash, and zucchini, can use the conveyor for picking up bins.

Figure 10.4 and 10.5 Harvest wagon, at the top. Harvest conveyor, hooked up at bottom.

Green beans are always harvested with the Pixall BH100 Bean Harvester, and potatoes are harvested using the potato digger. In addition to these machines, a truck should always accompany the bean harvester to hold bins, and the harvest wagon should be taken to the field with the potato digger, staged with two macro bins (Figure 10.6).

Crops that require use of macro bins include brussels sprout stalks, cabbage heads, cantaloupes, potatoes, pumpkins, sweet potatoes, watermelons, and winter squashes. Two macro bins can fit on the conveyor wagon, situated on either side of the conveyor's front. Up to three macro bins can fit on the harvest wagon. Two of the bins should be set up over the front and rear axles, which provide support. A third bin, if needed, can fit in the middle. Always position bins flush with the outer edges for ease in removing them with forklifts at the end of the harvest.

The harvest wagon is driven to the field by truck or tractor. Always connect a tractor when drive-row conditions are wet. Enter the field drive row from either the north or the south. If harvesting greens, bunched items, or root vegetables, park in the middle of the field. This will help harvesters to bring their full bins to the shade with less walking from either end of the field. If harvesting with buckets for crops like sweet corn, summer squash, peppers, eggplant, or cucumbers, then park at the first end that is pulled into. The wagon will traverse the length of the field at the end of the harvest to pick up bins down the row.

Figure 10.6 Macro bin.

Empty harvest bins are dropped along the length of the drive row for easy grabbing by the crew when needed (Figure 10.7). Empty bins are dropped for broccoli (when not using conveyor), potatoes, sweet corn, and sweet potatoes.

Harvest Order

Crops are harvested in order from those most affected by water loss to those least affected[12]. The exception is sweet corn, which is always harvested first, in the cool morning, to minimize conversion of sugar to starch. See Table 10.1.

Harvest Training

Workers are instructed in proper harvest technique. Refer to individual crop profiles in the CSA Crop Handbook. Harvest training covers the following elements:

- Technique, including which tools to use, how to use the tools, and knife safety
- Quality, including how to determine crop readiness, sort items, or cull low-quality produce
- Food safety, including scouting for bird droppings or other animal feces in the field or in contact with the cash crop
- Cleaning, including which crops need to be cleaned during harvest and how to clean them
- Bin use, with guidance on moving bins to shade or field edges, keeping a drag bin at all times, and how full to fill bins before starting new ones
- Benchmarks, including expectations for how long it should take to harvest

The harvest manager divides the crew by task. Certain crops will be harvested by all (e.g., lettuce greens), while other crops will require designated teams for harvesting,

Figure 10.7 Red harvest buckets dropped along drive row.

Table 10.1 Vegetable Crop Harvest Order.

	Harvest Order
1	Sweet corn
2	Spinach and leafy greens
3	Lettuce
4	Carrots with tops
5	Broccoli
6	Beets, turnips, radishes with tops
7	Cucumbers
8	Beans
9	Cabbages
10	Tomatoes
11	Leeks
12	Beets, carrots, turnips, radish roots only
13	Cauliflower
14	Potatoes
15	Peppers
16	Brussels sprouts
17	Celery
18	Onions
19	Winter squash
20	Summer squash
21	All remaining

Based on maximum permissible water loss, least to greatest.

Source: http://www.postharvest.org/Water%20relations%20PEF%20white%20paper%20FINAL%20MAY%202015.pdf

teams for cleaning, and teams for bunching (e.g., beet and turnip bunches).

When harvesting an entire bed (e.g., lettuce mix), teams of two can be sent to different sections of the bed (Figure 10.8). Each person will work a single row, facing one another and moving in the same direction toward the center of the field. When harvesting an entire field (e.g., summer squash or peppers), workers should always start in pairs from the same end of the field, with all moving in the same direction. Each person in a pair works on either side of a bed. When harvest is selective (e.g., beets or turnips), the harvest crew is divided into different roles. Harvesters will all move in the same direction when harvesting across multiple beds. Cleaners will follow in the path of the harvesters.

When bins are full, they are carried to the outer edges of the fields to be picked up in the drive row with the harvest wagon. When it is sunny, crops are carefully placed in the shade underneath or beside the wagon (Figure 10.9), or empty bins are stacked on top of the full bins to provide cover. Crops do not sit outside in the heat of summer for more than an hour to limit desiccation. When harvest takes longer than one hour, the wagon is loaded up and crops are taken inside the packing shed to be set in shade, hydrocooled, or stored in the walk-in cooler until they can be washed.

During harvest, the harvest manager checks the crew's work for correctness, consistency, and quality.

Recordkeeping

Notes are made on the number of row feet harvested for each crop. One full bed of double-row crops is 600 feet, whereas a full bed of a single-row crop is only 300 feet. Other notes are made regarding crop readiness, timing, or any issues observed in the specific field or planting (Figure 10.10).

Tomatoes are weighed at time of harvest, and weights are recorded by harvest date as well as by type of tomato: hybrid, heirloom, or paste. Bins are labeled with weight and tomato type.

Other Notes

The harvest manager is responsible for keeping track of the number of bins being filled, communicating with the pack shed manager about bin needs, and ensuring the filled bins are moved to the shade or the pack shed in a timely manner. Crops should not be sitting outside for longer than an hour in the heat of summer.

When there are more than eight harvesters in the field, two teams can be formed and split up between two crops. A second team leader is designated to manage the harvest of the second crop.

Figure 10.8 Paired harvesters.

Figure 10.9 On sunny days, bins are carried to the harvest wagon and placed underneath in the shade.

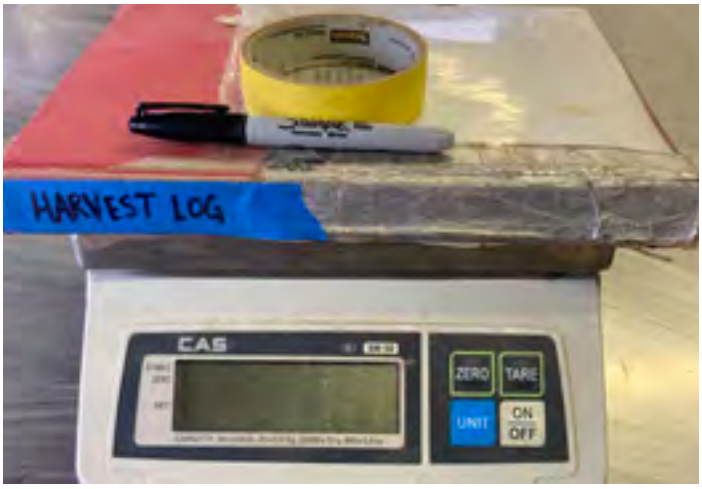


Figure 10.10 Recordkeeping.

11. SOP: PACKING SHED MANAGEMENT

The packing shed manager moves the harvested crops through the process of washing, sorting, storing, packing, and tabulating harvest totals and CSA share amounts.

Food Safety Protocols

Be sure all workers wash hands with soap and water prior to working with harvested crops in the packing shed. Water bottles are allowed in the shed, but no other food or drink is permitted.

Packing Shed Setup

All surfaces in the shed are cleaned and sanitized before use. Surfaces are sprayed with a water hose, scrubbed with brushes if needed, and squeegeed off. A handheld spray bottle filled with a 10 percent bleach solution is used to spray all cleaned surfaces for sanitization. The surfaces are left to air dry. The following surfaces should be cleaned:

- Roller conveyor
- All stainless steel tables
- Sorting table shared by the brush and barrel washers
- Brush washer belt
- Salad spinner lids and interior baskets
- Dunk tank edges

Check the cooler and reorganize if needed. Consolidate bins, remove empty bins from the cooler, remove any crops from the previous week to the northeast side of the cooler door for GleanKY to pick up, and reserve crops as needed for staff use. Any puddles of water should be mopped, and the custom fork hand truck should be used to move stacks of crops around to make more room. If workers will be bringing in macro bins, the path into the cooler is cleared, and a spot large enough to drop the bins is also cleared.

Next, each of the needed wash stations are set up. Compost bins are placed at the wash stations for workers to use. UK-CSA uses five wash stations:

1. Dunk tank and bubbler
2. Rinse conveyor
3. Barrel washer
4. Brush washer
5. Bunched washing station (outside)

Preparing and Using the Wash Stations

All of the wash stations run off a single hydrant along the south wall of the packing shed. The water pressure is insufficient to support the use of more than one wash station at a time. It is best to fill 1) the dunk tank, and then 2) the rinse conveyor reservoir. Once these tanks are filled, any of the other three stations may be used, but only one at a time.

The target number of workers for operating the wash stations are as follows:

- Dunk tank with bubbler—one or two workers to wash and spin, and an additional one or two workers to pack and weigh
- Rinse conveyor—one worker to load and one worker to unload
- Barrel washer—one or two workers to sort and weigh
- Brush washer—one worker to load and an additional one or two workers to sort and count
- Bunched washing station—two or three workers, with the optional third worker serving as runner

Some crops can be washed at more than one station. Consult the **Wash Line Selection Guide** (Table 11.1) or refer to crop profiles in the Crop Handbook.

Table 11.1 Wash Line Selection Guide.

Wash Line	*Crops Washed*
Barrel washer	Beets, carrots, parsnips, radishes, rutabaga, turnips
Brush washer	Bell peppers, cabbage, cucumber, eggplant, kohlrabi, pumpkin, summer squash, sweet peppers, watermelon, winter squash, zucchini
Bunched wash station	Beets, carrots, celery, fennel, ginger, green onions, leeks, turmeric, turnips
Dunk tank with bubbler	Arugula, bok choy, braising greens, broccoli, carrots, chard, collards, ginger, kale, lettuce, napa cabbage, spinach, sweet corn, turmeric, turnips
Rinse Conveyor	Celery, green onions, leeks, radish bunches, rhubarb
Unwashed	Brussels sprouts, bulb onions, cantaloupe, cauliflower, garlic, green beans, herbs, hot peppers, popcorn, potatoes, snap peas, sweet potatoes, tomatoes

11. SOP: PACKING SHED MANAGEMENT

Dunk Tank with Bubbler

Prior to filling the dunk tank, shown in Figure 11.1, connect the drain hose at the west end of the tank, and close the valve. The valve handle will be perpendicular to the hose line when it is closed. Adjust the Dosatron, shown in Figure 11.2, for the correct SaniDate 15.0 rate (indicated on tape at lower left corner of mounting board), and open the two Dosatron valves (ball valve handles). Then shut off the main valve on the PEX tubing coming off the main packing shed hydrant. Remove the Hudson float valve at the end of one of the PEX hoses from its hook on the north wall and set it inside the tank. Open the water valve to begin filling the dunk tank.

The float valve will shut off once the tank reaches 100 gallons. Turn the water valve off and return the float valve to its holder on the wall. Flip up the switch on the north wall to activate the bubbler. Crops are dumped into the tank from the east side, off of the roller conveyor, and washed crops emerge into bins on the west side. Loose greens are spun in the salad spinners for one to two minutes per spin (Figure 11.3), while other crops like bunched items are packed and counted into their bins after the wash. If using the dunk tank for multiple crops, check water clarity and use peracetic acid test strips to verify the SaniDate level is at the correct ppm.

Rinse Conveyor

If using the rinse conveyor (Figure 11.4) for crops, raise the machine to inspect the interior. If the interior is dirty, use a hose to spray out and drain completely. Remove and spray off the screens, if needed, and then replace. Once clean, open the two water valves, one marked "Circulation" only and the second for both "Circ and HP" (high pressure). Lower the white valve at the base of the machine to close off the drain hose. Lower and lock the machine into place.

When using this machine for crops, workers wear an apron to stay dry. The circulation spray bars can be lowered to spray closer to the crop surface. Loosen the screws above the machine to set the height of the spray bars and tighten the screw in place at the desired height. When it is time to load crops, raise the front curtain and secure it above the rinse conveyor with a bin or other weight. This keeps the curtain from blocking the first wash stream. Slowly empty the bin contents onto the conveyor belt. Turn the machine on for circulation and adjust the speed of the conveyor belt. A second worker at the opposite end should be ready to pack and count the washed crops into clean bins.

Figure 11.1 Dunk tank and bubbler.

Figure 11.2 Dosatron wall unit.

Figure 11.3 Salad spinners.

Figure 11.4 Rinse conveyor.

11. SOP: PACKING SHED MANAGEMENT

Barrel Washer

Inspect the interior of the barrel of the barrel washer (Figure 11.5) to ensure it is clean. Use a hose to spray down the inside, if needed. Before loading the machine, loosen the two screws on either side of the west side panel and raise the panel using the handle on top of the machine. Tighten the two screws to hold the panel in place in the raised position. This panel keeps the crops inside the barrel washer to finish the wash cycle before exiting.

When crops are ready to be loaded, turn the water valve on above the machine on the east side. Dump bins of roots into the barrel from the same side. Some items may need to be pushed by hand into the machine. Adjust the speed of the barrel on the control panel. Most roots are not washed in the barrel faster than the setting "4" to minimize any damage to the crop's outer layer. Most crops need 10 or more minutes to be thoroughly washed.. When crops are clean inside the barrel washer, turn on the Dosatron dispenser for the spray setting to wash crops for the last 45 seconds to 1 minute with SaniDate 15.0. After the SaniDate spray, lower the panel to allow the roots to exit the barrel onto the sorting table.

Brush Washer

Turn the switch box on to start the belt of the brush washer (Figure 11.6). Sanitize the loading belt with bleach solution. Adjust the Dosatron dispenser for the spray setting and turn on. Turn on the water valve on the north side of the machine, below the power switch. When loading crops, empty bins onto the belt. Adjust the last top brush higher or lower with the handle above the unit, accessed from the south side. Make sure the brush is in contact with the crop as it comes through the machine. Dump more bins of produce once the belt is clear but without overloading the sorting table or outpacing counters and sorters. A continuous supply of crops will keep everything moving through the machine at an even pace. The last bin load may need to be helped along through the machine by hand. Always raise the last brush before reaching in to pull any crops through.

The latex sponges at the end of the machine are replaced annually. Crops exit to the sorting table for sorting, packing, and counting.

Bunched Washing Station

When using the bunched washing station (Figure 11.7), workers wear rubber boots and an apron to stay dry. Two workers can manage the station at one time, facing each other from the north and south sides of the table. Be sure the table itself is clean and sanitized prior to use. Turn the water on at each of the two nozzles raised above the table. Adjust the spray pressure by twisting the nozzles, if needed.

Place unwashed crops on the west side of the table. Pass the crops through the water spray. Pack and count crops into clean bins, sitting on the east side of the table. Once a bin is filled, a runner can move the crops inside the packing shed to the cooler.

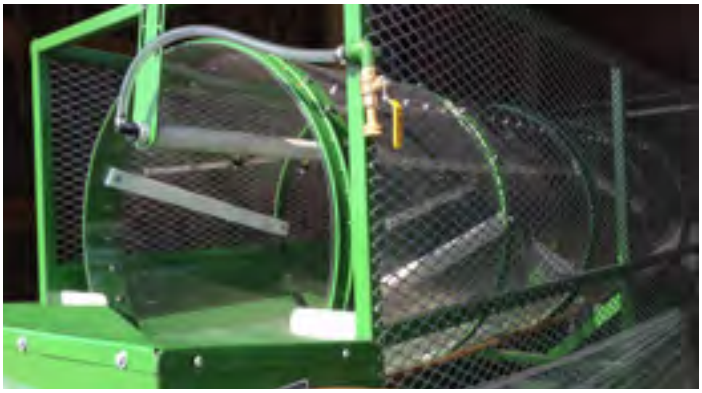


Figure 11.5 Barrel washer.

Figure 11.6 Brush washer.

Figure 11.7 Bunched washing station.

11. SOP: PACKING SHED MANAGEMENT

Packing Shed Training

Workers are instructed in proper post-harvest handling techniques. Refer to individual crop profiles in the Crop Handbook. Packing shed training covers the following areas:

- Food safety, including the importance of scraping field dirt off of one's boots prior to entering the shed, washing hands before handling produce, keeping all bins of crops off of the floor by sitting them on pallets or the roller conveyors, and using compost bins for any culled product or item that falls on the floor
- Wash line, including which wash stations to use for which crops, how to use each station, and which PPE is recommended
- Bin usage (Figures 11.10–11.18), including which bins to pack crops in, which bins are designated for compost, and the placement of empty or dirty bins under the roller conveyors to be washed later
- Sorting, which includes checking washed crops for bruises, injuries, soft spots, discoloration, or other malformation and sorting items into "seconds" bins or compost bins
- Counting and weighing, including which crops are counted individually and which are only weighed
- Recording, including which bins require labels with their count or weight and how to record washed crop amounts on the white board
- Storage, including where to place the crops in the cooler

Bagging Items

When bagging crops for the share, each worker receives a full bin from the cooler, a scale, a clean empty bin, and a roll of plastic bags (or a stack of paper bags) to use. The main stainless steel tables can accommodate four to six workers. The sorting table and roller conveyors can also be used as bagging stations. Two workers may need to share a scale. In this case, half of the workers fill bags and hand them off to others, who check the weight and adjust them on the scales.

The packing shed manager standardizes the packing for all workers by crop. Determine the ideal number of bags that can fit in one layer in the bin and how many layers can fit in each bin. All workers stick to the same number of bags per bin. When bins are full of bagged crops, they are stacked on a mini pallet. When stacks are four or five bins high, they are brought inside the cooler with the custom fork hand truck (Figure 11.8). The full bin count is recorded on the white board (Figure 11.9) to double-check that enough crops are being bagged to cover the share amount plus a 25-share buffer.

Bins that held loose, washed greens can be reused to hold bagged items.

Figure 11.8 Custom hand truck with forks.

Figure 11.9 Packing shed white board.

11. SOP: PACKING SHED MANAGEMENT

Recordkeeping

The packing shed manager is responsible for verifying accurate records of crops harvested, washed, packed, and loaded into the cooler.

Workers are tasked with labeling bins with counts when each bin holds a different quantity of the crop. Label counts for the following crops: cucumbers, eggplant, kohlrabi, peppers, Red Meat or Watermelon radishes , summer squash, and zucchini. Macro bins should be labeled with amounts on the lid or side handle for cabbage, cantaloupe, pumpkin, sweet potatoes, watermelon, and winter squash. Items that are boxed or bagged, like garlic and onions, should also be labeled with their final counts. Only tomato bins are individually labeled with the weights, as weights vary between bins. These bins should also be labeled by type: heirloom, hybrid, or paste. Equal proportions of tomato types are sent to each distribution location. Tomatoes are stacked according to their type inside Cooler 3.

Workers record their own bin weights and bin counts on the white board at the time of loading into one of the coolers. Records on the white board always include date of harvest, crop name, count or weight (use "#" symbol to denote pounds), and total amount. Scales are always tared to account for empty bin weight. When different bins are being used, the scale is not tared, and bin weight is subtracted from the scale weight. Refer to Table 11.2, **Bin Weight Reference**.

Figure 11.10 Dark-green bin.

Figure 11.12 Yellow bin.

Figure 11.11 Light-green bin.

Figure 11.13 Brown/orange bin.

Figure 11.14 Green, 12-inch hort bin.

Figure 11.15 Collapsible blue bin.

Figure 11.16 Red bucket.

Figure 11.17 Bread tray.

Figure 11.18 Tan bowl.

Table 11.2 Bin Weight Reference.

Bin Type	*Bin Weight*
Dark Green, bail arms, 13 inches tall	6.46 lbs
Light Green, bail arms, 10 inches tall	5.58 lbs
Yellow, 7 inches tall	3.96 lbs
Brown/Orange harvest, 10 inches tall	4.36 lbs
Green, 12 inches tall	5.60 lbs
Blue, collapsible, 10 inches tall	5.10 lbs
Red Bucket, 13 inches tall	1.18 lbs
Black Bread Tray, 6 inches tall	5.16 lbs
Tan Bowl	0.42 lbs

11. SOP: PACKING SHED MANAGEMENT

The packing shed manager transfers totals to the CSA weekly share list. Based on totals, quantities for the share are decided in conjunction with the harvest manager. Total pounds or counts are divided by 275 for 250 shares. This allows for a 25-share buffer for errors or farm-stand sales. When counts are close, the 25-share buffer is omitted. Numbers are rounded down to the nearest whole number. This will result in excess, which can be divvied up by distribution location and sold at the farm-stand sales. Extra items above share numbers should be pulled into blue bins or a bin that is clearly labeled as extra for the farm stand. Most of the extra items are sent to campus, and a handful are retained for on-farm. Record the number of extra items allocated to campus and farm for retail sales in columns to the right of the share numbers on the white board.

Example: On Friday, 207 summer squashes were harvested. On Monday, 178 were harvested, and 158 were harvested on Wednesday. This gives a weekly total harvest of 543. If 543 is divided by 275, the result is 1.97. This is very close to two, so if the 25-share buffer is omitted, two summer squashes can go to each of the 250 shares, and there will actually be 43 extra summer squashes. While this extra is less than a 25-share buffer and is not enough to add an extra squash to one of the two distribution locations, 43 is an adequate leftover amount to sell at the farm stand.

The final recordkeeping step is for the packing shed manager to transfer all harvest totals to the harvest log. At the end of the week, the actual CSA share breakdown for the week is recorded next to the projected CSA box list, in order to track proximity to projections and calculate share value. All white board items for the week are double-checked as being recorded in the harvest log. After this, the white board can be erased.

Storage

There are three coolers for different crops. Cooler 1 is the main, original cooler located inside the packing shed. This cooler is set at 32°F to 34°F year-round.

Coolers 2 and 3 are both part of the packing shed expansion and are set at 50°F to 55°F. Cooler 2 is the larger one, on the east side of the expansion. Cooler 3 is the smallest of the coolers, on the west side of the expansion. Cooler 2 holds macro bins of potatoes, winter squash, and watermelon. Cooler 3 is primarily dedicated for tomatoes. Both Coolers 2 and 3 can hold cucumbers, eggplant, summer squash, and zucchini based on available space. Smaller bins of winter squash and potatoes may also be stored in Cooler 3.

When loading crops in coolers, separate items to different sides for farm and campus. Make sure all labels on bins are facing outward to be read easily. Stack the same crops together on one mini pallet. Start a new mini pallet for a different crop.

Crops—except tomatoes—are covered with plastic pallet covers at the end of the day to retain moisture (Figure 11.19). Do not cover any crop that had insufficient cooling time to reduce field heat. Macro bins are lidded.

Figure 11.19 Plastic pallet covers.

Clean Up

All compost bins are removed from the building, consolidated into the compost macro bin or lidded in smaller barrels, or taken by end of day to the compost piles at the back of the farm.

Packing shed floors are swept and, if needed, sprayed with a water hose and squeegeed into the floor trench drain. Do not sweep water outside the doors. All dirty bins are stowed neatly under the roller conveyors. All tanks are drained and sprayed.

At the end of the day, hydrants are shut off, the cooler door is locked, and all packing shed doors are closed.

Other Notes

The packing shed manager double-checks that the number of bins in the cooler matches what is tabulated on the board. Counts on individual bins may have to be adjusted to evenly divide crops that are going to either farm or campus.

When multiple varieties of a crop are lumped together for the CSA shares (e.g., red and yellow bull's horn peppers), effort is made to equalize varieties for both CSA locations.

Extra items to be sold at the farm stand are pulled into blue bins that are designated for either campus or farm with labeling tape.

The clear poly curtains at the entrance of the cooler reduce energy loss from frequent opening and closing of the door (Figure 11.20). However, do not leave cooler doors open longer than necessary. During peak summer months, monitor the condenser inside the main cooler to be sure no ice is forming. If ice forms on the condenser, the cooler unit is turned off from the break box for an hour or more, until the ice dissolves. Overworking the condenser and allowing it to freeze can damage the components.

When loading crops onto the box truck, keep heavier items close to the rear doors to save energy in loading and unloading. Keep a stack close to the loading door that contains one bin of every item in the share for that week for easy offloading and quick setup. Blue bins with crops for the farm stand, and any other bins designated for farm stand, are also kept close to the loading door for ease in off-loading and separating from the CSA share items. Bins can be stacked four to five high in the truck. Maintain a center walkway within the truck, if able, for easier off-loading. Wheel wells are best used to hold bins of tomatoes. Tomato boxes are not stacked more than three high.

Figure 11.20 Plastic poly curtain.

12. SOP: HIGH TUNNEL AND SOLAR GREENHOUSE MANAGEMENT

Management of high tunnels and solar greenhouse structures includes several key topics:

1. Temperature and humidity control
2. Pest and disease monitoring
3. Structural repairs and safety

Temperature and Humidity Control

High tunnel cool-season crop management focuses on temperatures, cloud cover, and wind for optimal ventilation. Ideal high tunnel conditions for cool season crops will be 60°F inside with low relative humidity. Lowering humidity and temperature can prevent outbreaks of pests that thrive in warm, moist environments, notably aphids and whiteflies.

Start by checking the weather forecast for the following measurements:

- Daytime temperature highs
- Overnight temperature lows, which will include the low temperatures for the early hours of the following day, as the lowest temperature will often be reached between 4 a.m. and 7 a.m. the following morning
- Projected cloud cover (cloudy, partially cloudy, or clear)
- Wind speed, including the wind gusts and wind direction

Most prevailing winds at the farm come from the west and south. Venting instructions reflect opening doors (or curtains) away from prevailing winds, therefore the door or curtain to be opened for venting may change based on the forecast and the tunnel orientation.

Consult the chart for **High Tunnel Venting Protocols** to make management decisions (Table 12.1).

When temperature-sensitive crops are newly transplanted (particularly tomatoes), a few extra days are spent during their establishment to ease them into their new homes. This means not raising curtains as high to prevent bursts of cold air and occasional winds from shocking the new plants.

When row covering inside a tunnel for overnight low temperatures, workers should ensure that the row covers go all the way to the ground. In most cases, hoops are not required, and pavers are not needed to hold the covers down. Consult the chart for **High Tunnel Row Covering Protocols** to make management decisions (Table 12.2).

Tip: For efficient covering, two people should work together to cover plants (Figure 12.1). They can stand at opposite ends of the tunnel bed and pull the edges of the row cover over the plants and down to the soil level, keeping the fabric tight as they pull.

Figure 12.1 Two-person row covering.

Table 12.1 High Tunnel Venting Protocols.

Daytime Temperatures	*Cloud Cover*	*Venting Instructions*	*Open Time*	*Close Time*
Below freezing	Cloudy	Keep closed		
20°F-30°F	Clear	Open door away from prevailing wind halfway	9-10 a.m.	3-4 p.m.
30°F-40°F	Cloudy	Open door away from prevailing wind halfway	11 a.m.-12 p.m.	2-3 p.m.
30°F-40°F	Clear	Open door away from prevailing wind all the way	9-10 a.m.	3-4 p.m.
40°F-50°F	Cloudy	Open door away from prevailing wind all the way	11 a.m.-12 p.m.	2-3 p.m.
40°F-50°F	Clear	Open both doors	9-10 a.m.	3-4 p.m.
50°F-60°F	Cloudy	Open both doors	9-10 a.m.	3-4 p.m.
50°F-60°F	Clear	Open both doors, Curtain away from prevailing wind up 1'	9-10 a.m.	3-4 p.m.
60°F and above	Clear	Open both doors, Both curtains up all the way	9-10 a.m.	3-4 p.m.

12. SOP: HIGH TUNNEL AND SOLAR GREENHOUSE MANAGEMENT

Table 12.2 High Tunnel Row Covering Protocols.

Outside Temperature Lows	*Crops*	*Row Cover Weight*
30°F	Basil, Tomatoes, Peppers	Light/Mid
22°F	Asian Greens, Bok Choy, Green Onions (Parade), Napa Cabbage	Light/Mid
20°F	Arugula, Lettuce	Light/Mid
18°F	Beets, Celery, Radishes, Rutabaga, Strawberries, Turnips	Light/Mid
15°F	Asian Greens, Bok Choy, Green Onions (Parade), Napa Cabbage, Arugula, Lettuce	Heavy or Double Covers
12°F	Chard, Cilantro, Kale (Curly, Lacinato, Russian types)	Light/Mid
12°F	Beets, Celery, Radishes, Rutabaga, Strawberries, Turnips	Heavy or Double Covers
10°F	Carrots, Collards, Winter Radish	Light/Mid
Below 10°F	Green Onions (Evergreen Hardy White), Kale (Vates), Spinach	Light/Mid
Below 8°F	Chard, Cilantro, Kale (Curly, Lacinato, Russian types)	Heavy or Double Covers

Row covers are always removed first thing the next morning when temperatures are at a safe level, in order to expose plants to as much sunlight as possible and reduce relative humidity around the plants. Place bunched row covers not in use between beds of plastic or on outer edges inside the tunnels.

Thermometers connected to Wi-Fi and weather stations aid in decision-making by tracking temperatures inside the tunnels, under row covers, and at plant level (Figures 12.2 and 12.3). Many devices can be connected to a smartphone app for easy checking and monitoring even when away from the tunnel. Devices are placed in an area that is near plant level but where they will be easily seen and not stepped on. Weather stations are mounted on T-posts by bed edges in order to not interfere with row covers. Warmest temperatures will occur in the middle of the structures, while edges will be slightly cooler.

Figure 12.2 Thermometer connected to Wi-Fi.

Figure 12.3 Weather station.

12. SOP: HIGH TUNNEL AND SOLAR GREENHOUSE MANAGEMENT

Spring brings large windstorms to central Kentucky. Venting tunnels in windy conditions requires some alterations to the management plan in Table 1, based on wind speed and direction. High winds can cause damage to the plants inside tunnels, as well as to the structures themselves (Figure 12.4). In general, close doors and curtains against the prevailing wind and open those opposite to still allow ventilation. Consult the chart for **High Tunnel Wind Response Protocols** to make the best decisions (Table 12.3).

The solar greenhouse has unique temperature management protocols. This structure will heat up faster than most high tunnels and can also buffer low night temperatures better than high tunnels. The solar greenhouse is an ideal spot for getting more sensitive crops to survive in the middle of winter. Unlike the high tunnels, the solar greenhouse only has three venting options: east doors, west doors, and a south curtain. The south curtain is raised and lowered by aid of a winch (Figure 12.5). Turn clockwise or toward the south to open, and turn counter-clockwise to close.

The solar greenhouse will be vented more aggressively to get more airflow inside the structure. Consult **Solar Greenhouse Venting Protocols** for management decisions (Table 12.4).

Figure 12.4 Windstorm-shifted tunnel. Windstorms moved tunnels when anchors had not been fully installed. Note the structure has been picked up and moved diagonally in the plot.

Figure 12.5 Winch to raise solar greenhouse curtain.

Table 12.3 High Tunnel Wind Response Protocol.

Wind Speed	*Direction*	*Mitigation*
20 mph gusts or more	S, SW, SE	Close South Curtain
20 mph gusts or more	N, NW, NE	Close North Curtain
20 mph gusts or more	E	Close East Door
20 mph gusts or more	W	Close West Door
40 mph gusts or more	Any	Close Entire Structure

Table 12.4 Solar Greenhouse Venting Protocols.

Daytime Temperatures	*Cloud Cover*	*Venting Instructions*	*Open Time*	*Close Time*
Below freezing	Cloudy	May keep closed, or open East door and Curtain 1/4	11 a.m.-12 p.m.	2-3 p.m.
20^{0}F-30^{0}F	Clear	East door open, Curtain up 1/4	9-10 a.m.	3-4 p.m.
30^{0}F-40^{0}F	Cloudy	East door open, Curtain up 1/2	11 a.m.-12 p.m.	2-3 p.m.
30^{0}F-40^{0}F	Clear	East and West doors open, Curtain up 1/2	9-10 a.m.	3-4 p.m.
40^{0}F-50^{0}F	Cloudy	East and West doors open, Curtain up 3/4	11 a.m.-12 p.m.	2-3 p.m.
40^{0}F-50^{0}F	Clear	East and West doors open, Curtain up 3/4	9-10 a.m.	3-4 p.m.
50^{0}F-60^{0}F	Cloudy	East and West doors open, Curtain up all the way	9-10 a.m.	3-4 p.m.
50^{0}F-60^{0}F	Clear	East and West doors open, Curtain up all the way	9-10 a.m.	3-4 p.m.
60^{0}F and above	Clear	East and West doors open, Curtain up all the way	9-10 a.m.	3-4 p.m.

12. SOP: HIGH TUNNEL AND SOLAR GREENHOUSE MANAGEMENT

Pest and Disease Monitoring

Both insects and mammals can cause major damage to crops in high tunnels. Since these structures stay warmer year-round, insects and animals find refuge in tunnels. Pest outbreaks can also occur rapidly.

Monitor key insect pests like aphids, fungus gnats, spider mites, thrips, and whiteflies using yellow sticky cards placed at plant level. Cards are checked weekly, and notes are taken on number and species for each quadrant on the cards. The number and species of insects will help to determine the action threshold. A high tunnel monitoring form may be used. (See "High Tunnel Weekly Monitoring Form" in ID-235 by UK Vegetable IPM Team, 2018.)

When temperatures are more consistently above 65°F, biocontrol with lady beetles or other beneficial insect releases inside the tunnels is an option. However, unless the structures are netted, there is no guarantee these insects will stick around. Do not release beneficials if intending to manage pests by spraying pesticides, which could also have non-target effects on them.

Occasionally slugs will become troublesome, particularly for lettuce crops. A simple method of trapping is to bury a plastic cup in the soil until the lip is at soil level. Fill the cup partway with beer. Slugs will be attracted to the beer, fall in the cup, and become trapped. Slugs emerge at nightfall and in overcast weather, so have these in place overnight and during periods of prolonged cool, cloudy weather.

Small mammals like voles and mice should be monitored and controlled using snap traps. Plastic snap traps can be rinsed off and reused. Traps can be hidden under small boxes with an opening for entry. This box should be weighted with a small rock or paver to keep it from being disturbed. The box will obscure the trap to lure the pest inside, but it also keeps workers from accidentally stepping on them or disturbing them. Approximately four or five traps per tunnel may be needed. Traps can be set with a small amount of peanut butter, and bird seed may also help to attract them.

Larger mammals like groundhogs must be caught with larger traps via catch-and-release. Animals can be lured into the traps with pieces of melon. The traps can also be obscured with boxes or cardboard.

All traps are monitored daily. If any animal is caught in a snap trap, it is disposed of in the dumpster. The trap is rinsed, baited with peanut butter if needed, and reset. Slug traps can be rinsed and refilled weekly. If larger animals are caught in catch-and-release traps, notify the CSA manager and farm superintendent to assist with removal.

Structural Repairs and Safety

There are a few structural components to pay attention to within the high tunnels. The sliding doors slide along a horizontal track (Figure 12.6). Occasionally the bolts loosen and the door can fall off the track. It takes two people to fix, with one person lifting the door and the second on a ladder reattaching the bolt to the door.

When closing doors, be sure that they are secured within the braces to hold them tight.

Doors on the solar house are propped open with two pavers on each door (Figure 12.7).

Figure 12.6 Sliding door hardware.

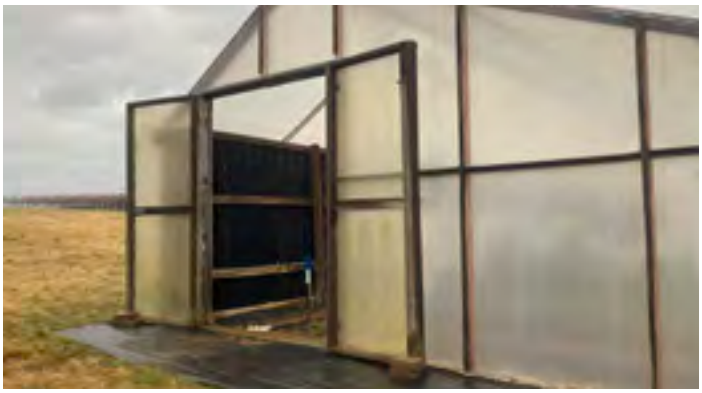


Figure 12.7 Solar greenhouse doors propped open.

12. SOP: HIGH TUNNEL AND SOLAR GREENHOUSE MANAGEMENT

When raising and lowering rolling side curtains, careful control is maintained during the entire raising and lowering process. These curtains are under tension, which increases as they are raised. If a worker loses a grip on the handle crank, it will ricochet back, which can cause injury. All workers must be trained on raising and lowering side curtains before attempting to use the cranks (Figure 12.8). In addition, when closing the curtains, workers walk the length of the sides and ensure the far ends are not snagged and have made contact with the baseboards. If any curtains have gotten caught, they are tapped down into place with one's foot (Figure 12.9).

With heavy snow, a broom or pole with a tennis ball on the handle can be used to gently push up the plastic from underneath. Workers start at the top and work the tool down the gothic arch to encourage the snow to slough off. This will help keep weight off the structure and allow sunlight into the structure for the plants.

During thunderstorms, the high tunnels are not safe places to continue working. Workers must leave the structures and, if shelter is needed, head to the packing shed.

Small tears in plastic are repaired with poly patch. The surface must be dry before adhering the poly patch over the hole. The patch is reinforced with tape around the edges. The poly patch will hold better when cut in a rounded shape rather than a squared one. Rounded edges are not as subject to peeling easily.

Any other structural issues that are spotted are reported to the CSA manager.

Figure 12.8 Handle crank on high tunnel side curtains.

Figure 12.9 Tapping curtain poles down with one's foot.

CSA Workbooks

In this section, two workbooks outline key components of the CSA planning process.

The **Share and Field Planner** includes worksheets for projecting shares, crop planning, and scheduling.

The **Fertility Planner** covers how to credit nitrogen in the soil and from cover crops to determine crop nitrogen requirements.

Click on the bolded titles to access and view the workbooks.

Appendix

Glossary

Backpack Spray — Method of pesticide application using a tank worn on one's back and dispersed with a handheld wand or blower. They can be powered manually or by gas.
Bare Ground — One of the production systems at UK-CSA, which describes the environment in which the plants grow, on bare soil that has been formed into beds.
Barrel Wash — One method of post-harvest handling to hydrocool and wash root crops that have had their greens removed, utilizing a long, rotating drum and water-spraying nozzles to dislodge soil.
Basket Weed — One method of between-row weed cultivation for thread-stage weeds, where weeds are uprooted or crushed by rotating metal bars arranged in a cylindrical shape referred to as a basket.
BCS — A walk-behind tractor used in tunnels and biointensive plots.
Beneficials — Insects that aid plants by pollination or by preying on insects that cause feeding damage to crops. A few examples include bees, parasitic wasps, lacewings, and assassin bugs.
Biointensive — One of the production systems at UK-CSA, characterized by smaller field (or plot) size and more plants being grown in each area. Frequently plants are grown on three, four, or six rows per bed to maximize yield on a smaller land area. Management of these plots is accomplished primarily with the use of a BCS walk-behind tractor and hand tools.
Blind Cultivate — The practice of cultivating a field without regard to the placement of the field rows, with the intent of disturbing the soil's top layer and uprooting newly germinated weeds.
Bolting — The biophysical process of a plant beginning to produce a flower stalk and set seed, which can result in lowered plant quality or a crop unfit for consumption.
Boom Spray — A method of pesticide application using a tractor's PTO-powered mixing tank and a spray bar that can be extended over the field and raised or lowered to apply the pesticides right above the plant canopy.
Broadfork — A hand tool with several sturdy tines that help break soil compaction when sunk below the soil surface. It is used in biointensive and tunnel systems.
Brush Wash — One method of post-harvest handling to hydrocool and wash vegetables that can withstand some agitation from rotating brushes. It is frequently used with cucurbits, peppers, and eggplants.
Bubbler — A method of injecting air into a dunk tank of water to create bubbling and agitation, which can wash crops like leafy greens more effectively when they are submerged.
Buffer Strips — Areas of field plots, frequently at the long edges, where a cover crop is grown instead of a cash crop to provide beneficial insect habitat, biodiversity, weed control, and more organic matter for the field.
Caterpillar Tunnel — One season extension structure that is smaller and easier to move than a high tunnel, using ropes laced from side to side over the structure's peak to keep the plastic held down tight; it is sometimes called a "cat tunnel" for short.
Chisel — One method of tillage frequently employed to help break down and incorporate the previous season's crop residues.
Compaction — The state of soil when soil aggregates are tightly compressed and air pockets have been reduced, hindering the flow of air and water as well as the growth of roots and plants.
Compost — Partially decomposed plant material that contributes to soil tilth by adding organic matter, increasing water-holding capacity, and retaining nutrients.
Coupler — An irrigation component that is used to link two sections of irrigation lines to each other.
Cover Crop — A crop that is not grown as a cash crop but is planted for nonmonetary benefits, like weed control and soil health.
CSA — Short for "community supported agriculture," it is a method of direct marketing a farm's products to a particular group that pays for their produce in advance of the growing season to offset up-front input and labor costs the farmer faces.
Curing — A method of post-harvest handling to dry the crop's outer skin and prepare it for long-term storage.
Direct Seed — One method of starting crops, in which seeds are placed directly in the field's soil at the time of planting.
Disc — A weed cultivation component that slices through residues when pulled behind a tractor.
Dosatron — A water-powered dosing tool used to precision-inject fertilizer or sanitizer into water lines.
Drag Bin — A bin placed in direct contact with the soil, below a second bin that is nested inside of it to hold the harvested crop; this bin is employed to reduce soil buildup and chance of contamination on the crop itself.
Drip Tape — One method of crop irrigation, wherein water flows through narrow plastic tubes and drips out of slits spaced apart at set intervals (6, 8, or 12 inches) on top of the tape; this tape can be laid on top of the soil or buried three to four inches subsurface.
DTM — Short for "days to maturity," this is the average number of growing-degree days from planting to harvest for a given crop variety. This value is sometimes calculated from direct seeding, or it can also be calculated from time of transplant.

Emitter — An irrigation valve that connects the header irrigation lines to the drip-tape lines in the bed and can be manually turned on and off.

Fertigation — The process of giving plants supplemental fertilizer by injecting it into the irrigation water.

Finger Weed — One method of in-row weed cultivation, using a tractor-pulled implement with flexible spinning tines to maneuver next to and between plants.

Flail Mow — One method of cover-crop termination, as well as management of crop residues, that involves chopping the biomass into small pieces that will decompose quickly.

Flame Weed — One method of blind-weed cultivation, when a propane-powered flame comes into contact with the soil surface to kill any newly emerged or emerging weeds.

Frost-free Days — The interval between the last expected frost at the start of the growing season and the expected first day of frost at the end of the season. The frost dates are determined based on when there is a 50 percent chance of frost for a given geographic area. In Zone 6b, the last frost date is around April 20, and the first frost date is around October 23. These dates can change from year to year.

FSMA — The Food Safety Modernization Act, enacted by the U.S. Congress in 2018, which outlines practices and requirements for food producers to better protect public health and prevent foodborne illnesses. For more information, see www.fda.gov/food/guidance-regulation-food-and-dietary-supplements/food-safety-modernization-act-fsma.

GAP — Short for "Good Agricultural Practices," this is a set of practices recommended for agricultural producers to prevent foodborne illnesses; an elective third-party audit can be given to certify that certain farm operations are in compliance with these protocols and may be required by certain buyers of a farm's products. For more information, see www.ams.usda.gov/services/auditing/gap-ghp.

Hardening Off — The process of slowly acclimating plants to outdoor weather conditions and fluctuations as they transition out of the shelter of a greenhouse or other protected environment.

Harrow — A weed cultivation tool with tines or teeth that are dragged across the soil surface to break up soil clods, residues, and kill weeds.

Haygrove — One season extension structure that consists of tall metal bows covered in plastic overhead but remains open to the elements on all four sides.

High Tunnel — One season extension structure that serves as an unheated greenhouse, harnessing the sun for warmth; this structure is covered above and on all four sides with plastic and is ventilated by the action of opening and closing doors and side curtains.

Hot Bed Weeder — A hand-weeding tool in the shape of a question mark, sharpened on all edges.

Hot Water Treatment — A cultural practice for preventing seed-borne plant diseases by heating seed to a given temperature threshold for a set amount of time to kill pathogens without harming the seed's viability.

IPM — Short for "Integrated Pest Management," this refers to a suite of practices to control and manage pests, including both insects, weeds, and diseases; practices may include cultural, mechanical, biological, and chemical methods of pest control.

Jang Push Seeder — A precision seeder that singulates seeds and can be easily adjusted and pushed to direct-seed a crop; this tool is frequently used in high tunnels and in biointensive field plots.

Knife Sheath — A simple knife carrier for workers to safely bring their harvest knives to the field, this carrier is made from recycled irrigation layflat and can be worn on a worker's belt and sanitized before and after use to keep the knife blade secure and clean between uses.

KYFSC — Short for "Kentucky Farm Share Coalition," this group oversees the CSA voucher programs and employer partnerships with CSA farms. For more information, see www.kyfarmshare.org/.

Living Mulch — A cover crop grown between rows or beds of plants that can be managed by mowing during the growing season; it covers the soil, outcompetes weeds, and adds organic matter to the field.

Manifold — A custom-built irrigation component used to divert the flow of water and reduce water pressure from the main irrigation supply lines before funneling water into individual fields.

MaterMacc Vacuum Seeder — A precision, PTO-powered seeder for direct-seeding crops into a bare-ground field.

Mechanical Transplanter — A tractor-pulled implement that is powered by a drive wheel to consistently time the planting of small transplants into a bare-ground field bed.

Nitrogen Credit — The amount of nitrogen presumed to be available to plants (PAN, or plant available nitrogen), calculated from compost, cover crops, and past fertilizer applications.

NOP — The National Organic Program, which is a federal regulatory program that sets the standards for organic certification. For more information, see www.ams.usda.gov/about-ams/programs-offices/national-organic-program.

OAK — The Organic Association of Kentucky, a nonprofit organization that connects and supports organic farmers in the state, and also supports the work of the KYFSC. For more information, see www.oak-ky.org/.

OFU — The Organic Farming Unit, located at the University of Kentucky's Horticulture Research Farm (HRF), consists of 35 acres that are USDA-certified organic. All organic-focused research, teaching, and extension efforts are connected to this unit; the UK-CSA is one entity at the OFU.

OMRI — The Organic Materials Review Institute, which provides guidance about which inputs are approved for certified organic use on farms. For more information, see www.omri.org/.

Organic — The USDA defines it as a labeling term that indicates a food or other agricultural product has been produced according to the USDA organic standards.

The organic methods integrate cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance and conserve biodiversity. For more information, see www.usda.gov/topics/organic.

Packing Shed — The location at the OFU where harvested crops are taken to be washed, processed, sorted, counted, packed, cooled, and stored.

Persephone Period — A term coined by Eliot Coleman, this is the time of year when daylength falls below 10 hours a day, and this time is categorized by reduced or little plant growth. In Central Kentucky, the Persephone Period starts around November 21 and ends around January 20.

Pest — A pest can be any entity that causes harm to a plant and may be an insect, another plant (like a weed), or a pathogen.

Plant Hardiness Zone — A zone is a defined geographic area based on the average annual winter minimum temperature, divided into 10°F sectors; these areas help to determine which plants will thrive in each location. The plant hardiness zone for Central Kentucky is 6b, which has an average winter minimum temperature of -5°F to 0°F .

Plastic Cultivate — A method of weed cultivation with custom tractor-mounted cultivation tools to remove weeds on the shoulders of beds covered in plastic mulch.

Plastic Mulch — A material installed over the soil on a raised bed prior to planting that acts as an inorganic barrier to weeds, reduces water evaporation and lessens soil erosion risk.

Plasticulture — One of the production systems at UK-CSA in which crops are grown on beds covered with plastic mulch.

Plow Pan — A section of the soil's profile where repeated tillage creates a hard, compacted layer that can create drainage problems and negatively affect plant health; it can be addressed by the action of subsoiling every few years.

Plug — The term for a small plant started in a tray within a greenhouse or other controlled environment that will be planted in the field.

Potting Media — The growing medium for a greenhouse-produced seedling.

Potting Up — The process of moving a greenhouse-grown plant from a small-cell tray to a larger-cell tray to allow for the plant to get bigger.

ProTek Net — A physical barrier to prevent insect damage and predation, made of a mesh net that allows only air, rain, and pesticide applications to penetrate down to the crop. The mesh sizes vary to correspond to the size of the pest that is desired to be excluded.

PTO — Stands for power take-off, this is the mechanism to transfer power from an engine on a tractor to an implement; the PTO shaft is the part of the implement that connects to the tractor for this power transference.

Rotation — A cultural practice to prevent insect and disease issues that necessitates moving crops within a given botanical family, or those sharing similar characteristics, from one field to another each year and allowing for a break of several seasons before the same crop family returns to that area again.

Rototill — A method of secondary tillage that breaks down soil clods and allows for a fine tilth of soil ready for planting.

Row Cover — A physical barrier used to prevent insect damage and predation in some circumstances but mainly employed to protect vulnerable crops from cold temperatures and wind. The covers will reduce light transmission corresponding to their thickness but still allow air and water to reach the crop underneath.

SaniDate — The trade name for a type of wash water sanitizer that is OMRI approved for food-safe agricultural production.

Scuffle Hoe — A type of long-handled tool that consists of a U-shaped, double-sided blade that rocks backward and forward with the motion of the handle to shallowly cultivate the top inch of soil. This tool is primarily used between rows of plants or on the shoulders of beds.

Seedbed Roller — This tool is a metal wire mesh drum with moveable metal dibbles that can be snapped into the mesh and arranged in different patterns and spacings on the drum's surface; the roller is manually pushed or pulled to create a dibbled grid for hand-planting in tunnel and biointensive field plots.

Solar Greenhouse — A type of season extension structure, also called a "deep winter" or "Chinese" greenhouse, that relies on the sun to heat a north-facing wall lined with black-painted water barrels or side-by-side, black, corrugated-metal walls filled with sand, which will retain the heat of the day and radiate it into the structure for significant temperature buffering overnight.

SOP — Short for "standard operating procedures," these documents provide step-by-step guidelines and how-tos, using words and visuals for the purpose of instruction, training, and standardization of on-farm operations.

Spade — A type of primary tillage that lifts soil with rotating spades rather than inverting soil.

Splicer — An irrigation component that connects two pieces of drip tape irrigation lines. When irrigation lines spring a leak, these components allow the leak to be cut out of the line and the two sides re-attached to one another to resume normal water flow.

Stale Seed Bed — A method of pre-plant weed cultivation over an established bed's surface that only shallowly cultivates the top one to two inches of soil for minimal disturbance.

Subsoiler — A tractor-pulled tool consisting of two long shanks that are pulled through the soil profile and create deep furrows to break compaction below the plow pan.

Tillage — The process of working and turning over soil to prepare it for planting.

Tilth — The physical soil qualities that are suitable for plant growth, including stability of soil aggregates, water-holding capacity, porosity, soil biota and microflora, and drainage rates.

Tilther — A long-handled tool activated by a battery-powered drill that incorporates soil amendments like compost and fertilizer prior to planting.

Tine Weed — A type of blind weed cultivation over the tops of emerged plants with the action of vibrating metal tines that remove thread-stage weeds.

Transplant — This word is used as a noun to refer to a plant plug from the greenhouse when it is ready for the field. When used as a verb, this refers to the process of planting a plug in the field. Plugs can be transplanted into both bare-ground and plasticulture systems.

Voucher — A monetary credit offered to UK employees on a UK health plan to reduce the cost of a CSA share.

Water Wheel — A tractor-pulled implement that uses metal wheels with preset dibbles to punch holes into beds covered with plastic mulch, inject water into the holes, and allow workers to hand-plant a plug into the bed.

Weed Seed Bank — The condition of a soil profile holding innumerable weed seeds that will germinate given the right conditions. Tillage is one of the primary ways that the weed seed bank is disturbed and amplifies the weed pressure for the following year, which must be managed by cultivations and cultural control tactics.

Wheel Hoe — A long-handled tool with a wheel that allows it to easily travel down the length of the bed while cultivating weeds located between beds or in wheel tracks within a field using an attached U-shaped, double-edged blade.

Wholesale — A marketing strategy to sell products in bulk to larger buyers, like restaurants, grocery stores, and food processors.

Winstrip — A type of tray used in transplant production in a greenhouse, with an offset grid pattern and slits on each of the individual plant cells that are located adjacent to an empty column, allowing for air pruning of roots, which reduces the risk of a plant becoming rootbound.

You-Pick — A marketing strategy to allow customers to come onto the farm to pick their own crops. At UK-CSA, the you-pick is a designated area of the farm and is limited to CSA members and their families only, as an included benefit of membership.

Resources

Seeds and Plants

Cottle Farms
www.cottlefarms.com

Fedco Seeds
www.fedcoseeds.com

Green Cover
www.greencoverseed.com

Hancock Seed Company
www.hancockseed.com

Harris Seeds
www.harrisseeds.com

Hawaii Clean Seed
www.hawaiianorganicginger.com

High Mowing Organic Seeds
www.highmowingseeds.com

Indiana Berry and Plant Co.
www.indianaberry.com

Johnny's Selected Seeds
www.johnnyseeds.com

Jones Family Farm
www.jonesfarmsnc.com/HowToOrderSPSeedsPlants.html

Lewis Seed Company
www.lewisseedcompany.com/

The Maine Potato Lady
www.mainepotatolady.com/productcart/pc/home.asp

Nourse
www.noursefarms.com

Seedway
www.seedway.com

Southern Exposure Seed Exchange
www.southernexposure.com

Territorial Seed Company
www.territorialseed.com

Tomato Fest
www.tomatofest.com

Totally Tomatoes
www.totallytomato.com

Uprising Seeds
www.uprisingorganics.com

Welter Seed and Honey Co.
www.welterseed.com

Wild Garden Seed
www.wildgardenseed.com

Tools

A.M. Leonard
www.amleo.com

Earth Tools
www.earthtools.com

Farmers Friend
www.farmersfriend.com

Johnny's Selected Seeds
www.johnnyseeds.com

Neversink Farm
www.neversinktools.com

Other Supplies

ARBICO Organics
www.arbico-organics.com

Berry Hill Irrigation, Inc.
www.berryhilldrip.com

Berry Seeder Company
www.berryseeder.com

BioSafe Systems
www.biosafesystems.com

Darling Ingredients
www.darlingii.com

Dubois Agrinovation
www.duboisag.com/us_en

Fetpak Inc.
www.fetpak.com

Gemplers
www.gemplers.com

Great Lakes IPM
www.greatlakesipm.com

Johnny's Selected Seeds
www.johnnyseeds.com

Martin's Nursery Wholesale and Retail
Liberty, KY

Nationwide Industrial Supply
www.nationwideindustrialsupply.com

Purple Mountain Organics
www.purpletools.net

QC Supply
www.qcsupply.com

Saveway Supplies Inc.
www.saveties.com

Schrock's/Lincoln County Produce Auction
Crab Orchard, KY

Seven Springs Farm Supply
www.7springsfarm.com

Ideal Sciences
www.tempstick.com

Uline
www.uline.com

Vermont Compost Company
www.vermontcompost.com

WebstaurantStore
www.webstaurantstore.com

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Slama, Jim, and Atina Diffley. *Wholesale Success.* New York: FamilyFarmed, 2013.

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Videos

UK Organic Farming Unit:
Bare-ground Production
Post-Harvest Handling
Dunk Tank Bubbler
AZS Rinse Conveyor

Food Safety/GAP:
Worker Health and Hygiene – Produce Best Practices Training
Pre-Harvest Wildlife Check – Produce Best Practices Training
Food Storage Boxes – Produce Best Practices Training

Click on the titles to view the associated videos.

UK-CSA Food Safety Manual

As a result of the farm going into wholesale production in 2015, 2016, and 2018, the food safety manual was developed as part of compliance with third-party GAP certification. Since then, this manual continues to inform staff, students, and visitors regarding the farm's active, ongoing commitment to food-safe practices.

UK-CSA COVID-19 Protocols

In the spring of 2020, the UK-CSA farm continued operations during the COVID-19 pandemic. This pandemic challenged the UK-CSA farm to re-evaluate on-farm practices for not only food safety but worker and customer safety as well. This document details how UK-CSA modeled safe and sustainable farming practices during the challenging time of the pandemic.

Click on the titles to view the full documents.

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CROP MANAGEMENT

Water Management for Vegetable Crops on Small Farms

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Introduction

Water management is critical in vegetable farming, regardless of farm size and crop type. Both inadequate and excessive water can lead to issues, with the extent of damage influenced by environmental conditions, soil properties and plant characteristics. This publication aims to help small-scale and diversified vegetable farms improve their water management practices for both open-field and high-tunnel production. While this content is intended for Indiana farmers, the information may also be relevant to growers in other humid and temperate regions.

Chapter 1. Common Vegetable Crops' Responses to Water Stress

Plants experiencing water stress — whether from too little or too much water — appear less healthy, become more susceptible to diseases and pests, and produce lower yields and unmarketable produce. Extreme water stress can lead to a complete crop loss. While various factors may prevent plants from achieving their maximum economic value, poor water management is often one of the most significant issues limiting crop yields at small farms.

Poor Water Management Leads to Unhealthy Plants

Insufficient water supply leads to drought, which progresses in stages. In the early stages, when the transpiration demand is high and roots cannot absorb water fast enough to meet the plant's needs, the stomata in the leaves close to conserve moisture. When stomata close, photosynthesis halts in most plants. Once conditions improve, the stomata reopen, and photosynthesis can resume within minutes. Over extended periods of drought, plants adapt by altering root growth, with drought-tolerant crops often developing deeper roots. This allows them to access water stored deeper in the soil, helping them recover and resume normal water and nutrient uptake, as well as their usual growth rate.

However, if drought continues, photosynthesis begins to decline significantly. Prolonged stress slows the development of new leaves and shoots, and existing leaves show signs of poor health, including nutrient deficiencies, increased susceptibility to diseases and pests, and wilting (Figures 1 and 2).

Too much water can also cause plant wilt, stunted growth and yellowing, similar to drought-related above-ground symptoms. When soil becomes waterlogged, oxygen is displaced from soil pores, creating an oxygen-deficient environment. This lack of oxygen inhibits root respiration and damages the roots. Damaged roots cannot supply the water needed for transpiration, so

Figure 1. *Broccoli plants exhibiting poor stand, slow growth, and leaf yellowing as a result of drought stress.*

Figure 2. *Comparison of peppers grown under deficient water supply (left row) and optimal water supply (right row) in a high tunnel.*

the stomata in leaves close and leaves wilt. Additionally, oxygen deficiency significantly reduces photosynthesis, decreases chlorophyll content, and accelerates leaf senescence, resulting in leaf yellowing (Figures 3-5). The injured root systems are also more susceptible to soil pathogens.

It's important to note that deep-rooted vegetable crops may recover quickly from extended drought once adequate water is restored. However, waterlogging for a few days can cause permanent root damage, which may limit the crops' productivity even after environmental conditions improve.

Figure 3. *The response of tomato plants to waterlogging. In the picture, the three tomato plants on the left experienced waterlogging; the three plants on the right grew under optimal conditions during the same period. The stressed plants exhibit wilting, yellowing and stunted growth.*

Figure 4. *The summer squash plants showed yellowing leaves when waterlogged.*

Figure 5. *Pepper plants wilted after an excessive rainfall.*

Figure 6. *Poor spinach seed germination at the near end of this bed.*

Figure 7. *Flower bud or early fruit abortion of pumpkins might be caused by drought stress.*

Poor Water Management Leads to Uneven Seed Germination

For directly seeded crops, such as salad greens, spinach, root crops, sweet corn and direct-seeded pumpkins, evenly distributed and adequate soil moisture is crucial for seed germination and uniform crop growth (Figure 6). Poor seed germination not only wastes seeds but also encourages weed growth due to the resulting uneven stand. Additionally, uneven crop growth caused by delayed germination complicates subsequent crop management. Ensuring proper soil moisture is essential for successful seed germination, which is the critical first step in growing direct-seeded crops.

Poor Water Management Delays Harvest and Reduces Yield

Insufficient water during flowering and fruit-setting stage can severely disrupt pollination and early fruit development, leading to flower bud abortion, poor or failed pollination, early fruit drop, and premature ripening (Figures 7 and 8). Although additional fruit may set after adequate water becomes available, losing early fruit set will delay harvest and lead to economic losses.

Figure 8. Misshaped fruit observed in a watermelon field suffering from severe drought.

Figure 9. Different stages of blossom end rot in tomatoes.

Figure 10. Different stages of blossom end rot in peppers.

Figure 11. Blossom end rot of watermelon.

It is important to note that deficient water supply is not the only factor that can cause flower and fruit abortion and misshaped fruit. A lack of pollinators, inadequate pollen, adverse weather conditions, poor overall plant health, and nutrient deficiency or excessiveness can also cause fruit abortion.

For fruiting vegetables such as watermelons, melons, and pumpkins, insufficient water not only affects fruit set but also leads to smaller fruit when drought occurs during fruit expansion, which negatively impacts yield.

A lack of water slows root expansion in root crops like carrots, beets and radishes. In leafy crops like lettuce and Asian greens, a reduced water supply stunts leaf growth. The end result can be a decrease in yield and income, either because the crop is harvested at a smaller size, or takes longer to reach the desired size, resulting in slower turnover rate of crops on one bed.

Poor Water Management Leads to Unmarketable Fruit and Reduced Quality

Water stress causes physiological disorders in fruits, reducing their marketability, which can lead to significant economic losses. One of the most noticeable fruit disorders related to water stress is blossom end rot (BER), frequently seen in tomatoes and peppers, and occasionally in watermelons (Figures 9-11). BER initially appears as a small dark or water-soaked area at the blossom end of the fruit. This spot darkens, enlarges, and dries out as the fruit matures. The fruit becomes unmarketable. Additionally, saprophytic pathogens may colonize the affected area, leading to fruit rot.

The direct cause of BER is a calcium deficiency in the developing fruit. However, a lack of calcium in the soil is rarely the key factor leading to BER. Calcium moves into plant roots with water, and moves from roots to shoots and developing fruits with water. The driving force for water movement is transpiration, and leaves demand much more water than developing fruit. When transpiration is inhibited even a little, developing fruit will receive a reduced amount of calcium along with the reduced water supply compared to leaves, because leaves have a stronger pull on the water than fruit. So, when transpiration is inhibited — whether due to limited water supply or diseases — it can lead to BER even with sufficient calcium in the soil. When tomatoes are grown in natural soil, BER is more commonly associated with deficient water supply than with other factors in Indiana.

As tomatoes and peppers set fruit over a long period of time, BER can occur at any time from the first fruit set until toward the end of the season, whenever stress conditions take place. In peppers, direct exposure to sunlight and high temperatures can cause sunburn, with symptoms similar to BER (Figure 12). Distinguishing between these factors can be challenging. However, the most dramatic damage of sunburn typically occurs under dry conditions combined with high temperatures or sun exposure.

Figure 12. *When the symptom occurred on the sun exposure side, the symptom is more likely caused by sunburn rather than BER.*

Ripening tomatoes and melons may crack or split when plants are suddenly exposed to excessive water, especially after an extended dry period. This physiological disorder is related to a rapid uptake of water by the fruit. The fast water uptake affects the strength and elasticity of the fruit skin, resulting in skin breaking (Figures 13-15).

Figure 13. *Severe tomato fruit cracking observed after heavy rains.*

Figure 14. *Cracking on tomato fruit observed following an extended irrigation event.*

Figure 15. *Watermelon fruit split after heavy rains.*

Figure 16. *Water-soaking observed on the edge of the watermelon flesh. The symptom is often observed after heavy rains at fruit ripening.*

In addition to external damage that makes fruit unmarketable, excessive water during the fruit ripening stages may reduce fruit sugar content and cause ripening disorders that reduce the internal fruit quality (Figure 16).

Priorities in Irrigation Management at Small and Diversified Vegetable Farms

Most small-scale vegetable farms grow a wide variety of crops, requiring farmers to juggle planting, harvesting and various crop management tasks. As a result, it can be challenging for farmers to dedicate sufficient attention to the irrigation needs of every crop. Additionally, small farms often have limited irrigation

capacity. Therefore, understanding how to prioritize irrigation management is crucial for maximizing overall efficiency at small farms.

To plan irrigation on small farms, a top priority should be placed on ensuring adequate soil moisture for germinating direct-seeded crops. If soil is moist, irrigation may not be needed. If not, soil should be thoroughly watered after seeding, with careful attention to prevent the germination zone from drying out. If a crust develops on the soil surface and prevents emergence, a light irrigation applied slowly can soften the crust to allow emergence.

In addition to soil moisture, temperature is another crucial factor affecting seed germination. Depending on the season, the temperature of the irrigation water — whether too warm or too cold — should be considered, especially for temperature-sensitive crops. More information about irrigation water quality is discussed in Chapter 5.

Newly germinated seeds and recently planted transplants have shallow roots, making them vulnerable to both excessively dry and overly wet topsoil conditions. It is generally more desirable to start with plenty of moisture in the soil before transplanting, rather than to try to wet the soil afterward. This approach ensures ample water is stored in the soil to support healthy root development, while reducing the risk of waterlogging in young plants. Even with plenty of moisture in the soil at the beginning, applying

Table 1. *Vegetable crops and growth period most critical for irrigation requirements.*

Crop	Most Critical Periods
Broccoli, cabbage, cauliflower, lettuce	head development
Carrot, radish, beet, turnip	root enlargement
Sweet corn	silking, tasseling, and ear development
*Cucumber, eggplant, pepper, tomato, melon, watermelon	flowering, fruit set, and fruit development
Bean, pea	flowering, fruit set, and development
Onion	bulb development
Potato	tuber set and enlargement

This table is adapted from Midwest Vegetable Production Guide (mwvguide.org)

* For continuously flowering plants such as tomatoes, peppers and cucumbers, the critical irrigation period extends through most of the growing season.

Sidebar 1. *Vegetable crops vary in the susceptibility to natural water fluctuations*

Vegetable crops vary in their susceptibility to natural fluctuations in water availability, with some suffering greater economic losses than others. In 2022, we conducted a demonstration comparing the growth of tomatoes, peppers, and eggplants under irrigated and non-irrigated conditions at two locations in Indiana: The Southwest Purdue Agricultural Center (SWPAC) in Vincennes and the Pinney Purdue Agricultural Center (PPAC) in Wanatah. At both locations, crops were grown on plastic-covered beds, with irrigation provided through a single drip tape placed beneath the plastic mulch. In irrigated plots, water was applied daily as needed to maintain optimal soil moisture in the top foot of soil under the drip tape throughout the monitoring period.

At SWPAC, plants grown without irrigation experienced significant drought for most of the season, leading to substantial yield reductions. Marketable yield of tomatoes, in particular, decreased by 73% compared to those grown on irrigated beds, while pepper and eggplant yields declined by 17% and 20%, respectively. At PPAC, drought was less severe, resulting in higher overall crop yields than at SWPAC. Nevertheless, the absence of irrigation still caused yield losses in all three crops, with peppers experiencing the greatest marketable yield reduction at 37%. Despite Indiana often receiving adequate precipitation, erratic rainfall distribution makes irrigation essential for achieving acceptable yields in fresh-market tomatoes, peppers, and eggplants.

However, it is not uncommon for watermelons to be grown on dry land in southern Indiana. A three-year study comparing seedless watermelons grown on irrigated and non-irrigated lands revealed that, although plants grown on dry land exhibited smaller vine coverage during drought periods, a yield reduction, approximately 16%, occurred in only one of the three years. In the other two years, yields were comparable between the irrigated and non-irrigated conditions. This study indicates that watermelons generally tolerate natural fluctuations in water availability, and in most years, yield may not increase with irrigation in Indiana.

a small amount of water and fertilizer solution to each transplant at transplanting or shortly after planting is recommended.

Close attention should be given to high-value crops during critical irrigation periods, as fluctuations in soil moisture can greatly impact both yield and marketability (Table 1). It is important to note that susceptibility to water-related disorders varies among cultivars. For instance, cherry tomatoes rarely experience BER, while fruits of certain slicer tomatoes and Roma tomatoes may often develop BER, and some heirloom tomato cultivars are particularly prone to splitting as they ripen. Farmers should consider the specific water sensitivities of different cultivars and apply tailored water management practices accordingly.

During the early growth stage of fruiting vegetables, plants are generally more tolerant of drought. Moderate drought can encourage deeper root growth, resulting in more resilient plants later in the season. At the final fruit-ripening stage, when the fruit has reached its full size and is undergoing chemical changes to enhance flavor, color, and aroma, reducing water supply can actually benefit flavor development. Drier conditions are often preferable during these phases.

Chapter 2. Principles of Water Management on Small Farms

Annual precipitation in Indiana generally meets the water needs of most crops. However, the erratic distribution of rainfall throughout the growing season makes effective water management essential when producing crops as a business. This management must address both drought conditions and the risks of excessive water after heavy rains.

A deep understanding of soil and its relationship with water is critical for successful water management. The rate of water infiltration into the soil determines how quickly water is absorbed and the likelihood of waterlogging or runoff after significant rainfall. The soil's water-holding capacity determines the maximum amount of water it can retain after heavy rainfall, the upper limit for water application during a single irrigation event, and the desired frequency of irrigation. Key soil characteristics — texture, structure, slope, organic matter content, compaction, and water table — collectively influence the soil-water relationship and play a crucial role in effective water management.

Managing Excessive Water

Natural soil properties and field topography are fundamental for water infiltration and drainage and determine the risk of waterlogging at a given location. While the type of soil is hard to change, various approaches to improve soil health, such as cover cropping and reduced tillage, can enhance water infiltration and drainage of naturally poorly drained soils. Additionally, understanding the farm's topography and incorporating a well-designed water drainage system early in the planning stages can be highly effective in directing surface water away from crop areas, thereby reducing the risk of waterlogging and enhancing crop production.

Figure 17. *Rainwater seeping into a high tunnel from the sides.*

High tunnel and caterpillar tunnels are commonly used on small farms. While these structures prevent rainfall from reaching the crops directly, the water that runs off the plastic accumulates within a few inches of the tunnel edges. If this excess water is not redirected, it can seep into the high tunnel, complicating water management (Figure 17). In cases where irrigation falls short of meeting crop water needs inside the high tunnels, water entering from the tunnel sides may benefit crop growth, leading to better plant performance of the side rows. However, when ample irrigation has already been provided, excess water from outside the tunnel could potentially cause waterlogging on the side rows. This issue can be easily overlooked because the waterlogging

Sidebar 2. *Estimating Plant Water Needs*

Estimating plant water needs is based on the estimated water use by a non-stressed, well-watered grass or alfalfa crop that completely covers the ground, plus evaporation. The estimate of plant water use plus evaporation is called reference or potential evapotranspiration, abbreviated PET. PET is calculated based on weather conditions. Most healthy, well-watered vegetable crops at full growth will use about the same amount of water as the grass or alfalfa; taller crops or staked crops will use a little more. Earlier in the season, when vegetable plants are smaller, the water use will be less. Crop coefficients (Kc) have been developed to convert PET into expected evapotranspiration for specific crop (ETc). The crop coefficients take into account the specific crop and the stage of growth.

Reference evapotranspiration (PET) is available from the National Weather Service and the Indiana State Climate Office. These two articles describe how to find the relevant information: *Reference Evapotranspiration forecasts across Indiana*, *Monitoring potential evapotranspiration across Indiana*. For a detailed explanation of the evapotranspiration method and suggested crop coefficients (Kc) for vegetable crops, refer to *Crop evapotranspiration – Guidelines for computing crop water requirements - FAO irrigation and drainage paper 56*.

may occur deeper in the soil; above-ground symptoms may not appear until several days after the stress; and various pathogens may be isolated from the damaged roots and plant stems, complicating diagnosis.

The *Indiana High Tunnel Handbook* provides suggestions for improving drainage when constructing a high tunnel, and the article '*Water Drainage at High Tunnel Improved*' by Missouri State University provides an example of installing drainage tiles along the sides of a high tunnel. Additionally, growing crops on raised beds may prevent waterlogging from occurring in the part of the soil where the majority of the roots are located.

Managing Irrigation

During periods without rainfall, irrigation is crucial to ensure acceptable crop production. Consider the following factors for successful and effective irrigation management.

- Plant water needs
- Soil water-holding capacity
- Root structures
- Irrigation system capability

Plant Water Needs

During the peak of summer, most full-grown vegetable crops use 1 to 1.5 inches of water per week (*Sidebar 2: Estimating Plant Water Needs*), which equates to approximately 27,000 to 40,500 gallons per acre. For crops grown on a 3-foot-wide by 50-foot-long bed, this translates to about 100 gallons of water per bed per week during the summer. In a 30-foot by 96-foot-high tunnel, it requires about 1,500 to 2,500 gallons of water weekly. Although this may seem like a large amount of water, a significant portion of the water often comes from precipitation or soil moisture accumulated from heavy rains, either during the growing season or before planting in open-field production systems in Indiana.

Soil Water-Holding Capacity

Effective irrigation planning requires a comprehensive understanding of moisture content in the soil. If this is not fully considered, there is a risk of overwatering. Conversely, the risk of underwatering is equally critical. Soils that hold less water can quickly dry out without additional rainfall or irrigation. Typically, heavier soils retain more water than lighter ones, but organic matter content, soil structure, and other characteristics also play crucial roles in determining how much water the soil can supply after a heavy rain or through irrigation event (*Sidebar 3: Soil Water Relationships and Total Available Water for Soils of Different Textures*).

On a larger production scale, the USDA's Natural Resources Conservation Service offers the *Web Soil Survey*, a tool that provides detailed information about soils across the state, including the available water capacity of specific soils. However, this tool may be less practical for small-scale farmers, particularly in urban areas where construction may have significantly altered topsoil characteristics, or where soils have been heavily amended with organic materials, altering their water-holding capacity. In such cases, laboratory analysis is needed to accurately determine the soil's water-holding capacity. For most small-scale farmers, however, general knowledge and experience are usually sufficient for irrigation management. Soil moisture sensors, which are discussed in detail in Chapter 3, offer additional support for fine-turning irrigation practices.

Root Structures

Root condition profoundly impacts crop yield, health, and resilience to environmental stresses. However, due to their underground nature, root status is easily overlooked. While the general root structures of specific crops are genetically determined (*Sidebar 4: Root Structures of Tomato and Watermelon*), cultural practices including water management can significantly influence root growth, which in turn affects crops' irrigation needs.

When ample water is available in the topsoil, roots are generally less likely to penetrate deeper into the soil (Figure 18). Similarly, when soil conditions are dry and irrigation only wets a small area, roots tend to remain within the moist zone, avoiding drier regions. In both cases, the irrigation management practices limit root expansion. Similarly, when plants are grown in pots with soilless medium, the root volume is confined by the size of pot (Figure 19).

Limited root growth does not mean lower yields. In fact, excellent yields can be achieved in soilless systems where roots are restricted to a small volume. Maximizing yields in these systems requires intensive crop management, including frequent irrigation – sometimes as often as every few minutes – combined with fertigation to consistently supply water and nutrients to the small roots. However, given the limited root system in these systems, even a brief disruption in water and nutrient supply can lead to significant yield loss.

Conversely, when crops are grown in soil without physical barriers to root expansion and are exposed

Figure 18. *The cucumber plant roots accumulate near the emitters of the drip tape. The plants were grown in a high tunnel, where water was frequently supplied through drip irrigation.*

Figure 19. *The tomato plants are grown in 3-gallon bags with soilless medium.*

Sidebar 3. *Soil Water Relationships and Total Available Water for Soils of Different Textures*

Concepts of soil water relationships

Saturation: all the empty space between soil particles is filled with water. Plants may suffer waterlogging stress due to the lack of oxygen.

Field capacity: water in large pores has drained by gravity. Field capacity is the optimal soil moisture status for plant growth.

Permanent wilting point: the remaining water is held so tightly to soil particles that plants can no longer extract water from the soil.

Total available water: the amount of water available for plants to take up, which is the difference between soil water content at field capacity and permanent wilting point.

The information is adapted from Irrigation of field crops in Indiana: a guide for evaluating irrigation potential on your farm, 1977. ID-119, Purdue Extension

* Soil testing laboratories often offer services to assess soil texture. Additionally, the Soil Texture Calculator developed by NRCS provides a tool for farmers who want to perform this calculation by themselves.

Total available water for soils of different textures in Indiana

Soil Texture*	Inches per foot soil
Sand	0.6
Sandy loam	1.3
Loam	1.8
Silt loam	2.2
Clay loam	1.9
Clay	1.8

Sidebar 4: *Root Structures of Tomato and Watermelon*

The root structures of common vegetable crops grown in a natural environment reveal fascinating patterns and adaptations. The descriptions and root illustrations are adapted from "*Root Development of Vegetable Crops*" 1927, by John E. Weaver and William E. Bruner, McGraw-Hill Book Company, Inc.

Tomato

A tomato plant's roots can occupy soil up to 2 to 2.5 feet on all sides of the plant and extend to a depth of up to 3 feet. Generally, they have numerous and profusely branched lateral roots growing from the base of the stem. These lateral roots may extend horizontally outward or vertically downward. Mid-season, when the plants are actively blooming, the root system occupies soil approximately 1.5 feet around the plant and reaches a depth of 1 foot. In mature plants, the roots spread up to 2.5 feet on all sides and penetrate 2 to 3 feet deep into the soil.

Cucurbit plants

Unique to cucurbit plants of all kinds, their root growth spreads widely in relatively shallow soil. In early development, a few but very strong lateral roots grow horizontally within the top foot of soil, often exceeding the spread of the vines above ground. Most transplanted cucurbit plants lack a taproot so that the main laterals are grown near soil surface. Even for directly seeded plants, when a strong taproot can extend beyond 3 feet deep, the main lateral roots still occur within the top foot of soil and spread as wide as the vines. These lateral roots have numerous branches growing in all directions, forming an extensive root system that can occupy mostly surface soil areas up to 30 feet in diameter.

Root structure of a tomato (left) and a watermelon (right) plant.

throughout the season to cycles of soil moisture from full saturation to gradual dry down, crops like tomatoes can develop extensive root systems. These large root systems are better equipped to handle environmental fluctuations, such as drought or excess moisture, and can access a broader range of stored soil water and nutrients later in the season. Under these conditions, crops often thrive with less need for intensive inputs.

Considerations for Irrigation Frequency

We've discussed that irrigation frequency should take root status into account. But when should intensive root zone management be prioritized, and when should extensive root growth be encouraged? When high-value crops like tomatoes and cucumbers are grown in high tunnels or greenhouses, frequent irrigation that maintains soil moisture at field capacity is often preferred. This approach typically results in earlier harvests, higher yields, and consistent fruit quality, ensuring high economic returns. Depending on soil type, irrigation may be applied once or multiple times a day.

Conversely, when tomatoes, peppers, and melons are grown in open-field under natural environmental conditions with limited resources, irrigating only when the soil dries out may be more beneficial. While this method may not always result in maximized yields, the moderate water stress generally encourages deeper root growth, improving the plants' resilience to environmental stresses and enabling them to thrive with minimal intervention. Methods for determining soil moisture status are discussed in Chapter 3.

Other factors also influence irrigation frequency decisions. For crops grown in well-drained sandy soils, frequent irrigations that apply smaller quantities of water are advisable. This will reduce nutrient leaching by avoiding large applications that would be necessary if applied less frequently. In addition, sandy soils often require frequent irrigation because they don't hold enough water for longer periods. In contrast, in a soil with a larger water holding capacity less frequent irrigation would make sense. Less frequent irrigation may also be more effective in soils that are poorly

Figure 20. Different types of timers are used to control automatic irrigation systems on small farms.

drained, or in those with low permeability in which water does not move through the soil quickly. In these soils less frequent irrigation will reduce the risks of waterlogging due to unanticipated and excessive rainfall and the associated plant stress. Because these soils often retain a significant amount of water, plants are less prone to drought even with less frequent irrigation.

On small farms, irrigation frequency is often constrained by system capabilities. Without an automated system, applying irrigation more than once per day may not be practical. When frequent irrigation is necessary, many farms use automatic systems controlled by timers connected to the water source (Figure 20). These systems significantly reduce labor for irrigation management. However, most timers require regular monitoring and maintenance to ensure proper operation. Irrigation schedules controlled by timers should be promptly adjusted to account for rainfall, optimizing water use and preventing over-application.

Chapter 3. Estimating Soil Moisture Status

Feel-and-Appearance Method

As discussed in Chapter 2, effective irrigation planning requires a thorough understanding of soil moisture conditions. The feel-and-appearance method is a widely used approach for assessing soil moisture. The article "*Estimating Soil Moisture by Feel and Appearance*" provides detailed explanations of this method for different soil types. This method typically offers insights into the soil moisture status of the top 2 to 4 inches. When used with a soil probe, it can be extended to evaluate soil moisture levels at depths of 8 to 10 inches.

For shallow-rooted crops, such as leafy greens, the feel-and-appearance method is generally sufficient for managing irrigation. However, for deep-rooted crops like tomatoes, it is important to assess moisture in deeper soil layers. This can be difficult using the feel-and-appearance method, especially when the surface soil is dry (Figure 21). In such cases, soil moisture sensors provide a valuable tool for assessing soil moisture status at greater depths.

Soil Moisture Sensors

A variety of soil moisture sensors are commercially available, offering a wide range of prices, sensitivities, accuracies, and capabilities for estimating soil moisture levels of different soil depths and volumes.

Soil moisture sensors can be broadly classified into two main groups. One group measures or estimates the volumetric water content (VWC) of the soil, expressed as a percentage or in cubic meters of water per cubic meter of soil (m^3/m^3). The second group measures soil tension, which is the force required by plant roots to extract water from the soil, expressed in centibars (cbar). Each type of soil moisture sensor has its own advantages and limitations. For a detailed explanation of the sensors and how to install the sensors, refer to "*Improving Irrigation Water Use Efficiency: Using Soil Moisture Sensors*" by Michigan State University Extension.

***Figure 21.** Using a soil probe to excavate soils for estimating moisture content. The soil moisture levels shown in the images represent conditions at approximately field capacity (left), permanent wilting point (right), and an intermediate state (middle) of a sandy loam soil. Note: It was significantly easier to penetrate the soil profile when the soil was wet (left) compared to when it was dry (right).*

Tensiometers, a type of soil water tension sensor, provide an affordable option for assessing soil moisture. These devices provide readings that directly reflect the water stress experienced by plant roots, making them easy to interpret. Tensiometers have various tube lengths, with the most common being 6 inches, 12 inches and 18 inches, used to measure soil moisture

at corresponding depths (Figure 22). However, tensiometers require frequent maintenance, especially in dry conditions, respond slowly to changes in soil moisture, and often require manual reading and data collection.

Sensors that measure volumetric water content (Figure 23) respond quickly to changes in soil moisture. While some models require manual readings, most modern sensors automatically record data using integrated loggers, such as the Onset Hobo® MX2306, or connect with separate data loggers like the METER TEROS 12, which enable remote data access. However, these sensors are generally more expensive than tensiometers. Some models incorporate multiple individual sensors to measure soil moisture content at various depths, but this significantly increases the cost of the sensors.

Multiple Ways of Using Soil Moisture Sensors

Irrigation management involves decisions about when, how long, and how often to irrigate. While soil moisture sensors can be valuable tools, they are not a one-size-fits-all solution that will automatically provide these answers after installation. Instead, it is essential to have a plan that identifies the key questions in the irrigation decision-making process, and to strategically select the appropriate sensor types, and install them at the targeted location. Below are three ways we have found soil moisture sensors particularly helpful in guiding irrigation decisions.

1. Using soil moisture sensors to guide when to irrigate

We often use tensiometers for this purpose and find them helpful. The tensiometers measure soil water tension, which is close to zero when the soil is saturated, indicating that no irrigation is necessary. At field capacity the tensiometer may read from 5 to 40 centibars (cbar), depending on soil texture (Table 2). As the tension reading increases, it signals that the soil is beginning to dry out. At this point, we consider weather conditions, crop growth stages, and the specific soil depth being monitored to decide whether immediate irrigation is needed.

Unlike tensiometers, sensors that measure VWC have high values when the soil is wet. As the soil dries, the VWC value decreases, in contrast to the increasing tension readings of tensiometers as soil dries. If water is applied to already saturated soil, the VWC reading will spike before gradually decreasing as the soil approaches field capacity. This is different to tensiometers, which remain around zero in saturated soil. Some experience is required to interpret the VWC readings and changing

Figure 22. *Installing a tensiometer in the soil.*

Figure 23. *Sensors measuring volumetric water content were placed at different soil depths. The photo was adapted from Dong, Y. (2023). "Irrigation Scheduling Methods: Overview and Recent Advances."*

trends in order to determine whether the soil is merely draining or actually drying out. Therefore, when using VWC sensors to decide when to irrigate, it's crucial to accurately determine the VWC readings at field capacity for the specific soil and to initiate irrigation only if the sensor reading is below field capacity. The practical method to determine VWC readings at field capacity can be found in "*Principles and Practices of Irrigation Management for Vegetables*" by the University of Florida, IFAS Extension.

In precise irrigation management, an irrigation threshold is established based on the allowable percentage of available water depletion. Irrigation is initiated when this threshold is reached. Table 2 shows tensiometer readings that correspond to 20-25% depletion of available water for different soil textures. For drought-sensitive crops or those in critical growth stages, irrigation should begin when water depletion reaches or approaches 20-25% at the soil depth where the majority of roots are located. This means tensiometer readings

for the corresponding soil textures should be maintained at or below the values listed in the table for 20-25% depletion.

When using sensors measuring VWC, farmers may find it challenging to adopt precise irrigation management practices based on a threshold. This difficulty arises partly because converting the water depletion threshold into specific sensor readings requires accurate estimations of the sensor readings at both field capacity and the soil's permanent wilting point (*Sidebar 5: Formula for calculating percent water depletion and converting percent soil water depletion to sensor volumetric water content*). Estimating these values involves tracking soil moisture changes from full saturation to the permanent wilting point – a complex task, especially if sensors are installed for only part of the growing season.

Table 2. *Soil tension values for different soil textures for use in scheduling irrigation*

Soil Texture	Field Capacity	20-25% Depletion of Total Available Water
	Soil Tension Values (in centibars)	
Sand, loamy sand	5-10	17-22
Sandy loam	10-20	22-27
Loam, silt loam	15-25	25-30
Clay loam, clay	20-40	35-45

This table is adapted from the Midwest Vegetable Production Guide (mwvguide.org)

Regardless of the sensor type, precise irrigation management is more effective when soil moisture sensors are integrated with automated irrigation systems that trigger irrigation as soon as the threshold is reached. While implementing the automated systems is possible for small-scale farms, farmers need to weigh both the costs and maintenance of the automated system in the decision-making process.

2. Using soil moisture sensors to fine-tune an irrigation schedule

Both types of soil moisture sensors are suitable for fine-tuning a preset irrigation schedule controlled by a timer. Small farmers may use this system to grow high-value crops, such as tomatoes and cucumbers, in a high tunnel or greenhouse. Irrigation may be scheduled multiple times a day, depending on crop stage. Sensors are usually installed at a depth of 10-12 inches beneath the plants, considering most root activity occurs within the top foot of soil in frequently irrigated crops.

Sidebar 5: *Formula for calculating percent water depletion and converting percent soil water depletion to sensor volumetric water content.*

- Percent Water Depletion = [1- (Sensor VWC-PWP)/(FC-PWP)]*100
- Sensor VWC = FC – [(SWD*(FC-PWP)/100]
- VWC: Volumetric Water Content (m^3/m^3)
  PWP: VWC at permanent wilting point (m^3/m^3)
- FC: VWC at field capacity (m^3/m^3)
- SWD: Soil water depletion (%)

The soil is often well-watered at the start of the season. An initial irrigation schedule is established to maintain optimal soil moisture for young plants. As the plants grow, the sensors may detect a declining trend in soil moisture content or an increasing trend in soil tension, indicating that the current irrigation schedule is not meeting the plants' increasing water demands. In response, the irrigation duration or frequency may be increased to stabilize and maintain consistent soil moisture levels. When the volume is increased, it is important to avoid over-irrigation that wets soil beyond the root zone. (That will be discussed in the next section.) If soil moisture content continues to decrease, further adjustments to the irrigation amount may be necessary.

Typically, as plant growth slows down and begins to decline later in the season, plant water needs decrease. In such cases, sensors may show a general trend of gradual rise in soil moisture, signaling the need to reduce the irrigation amount. It is important to note that, when the soil is close to field capacity, tensiometers cannot detect soil saturation. Sensors measuring VWC are more helpful in detecting possible excess water application.

Table 3. *Estimated effective rooting depth of common vegetable crops.*

Shallow (6-12 inches)	Moderate (18-24 inches)	Deep (> 36 inches)
Beet	Cabbage, Brussels sprouts	Asparagus
Broccoli	Cantaloupe	Lima bean
Carrot	Cucumber	Pumpkin
Cauliflower	Eggplant	Sweet potato
Celery	Pea	Watermelon
Greens & herbs	Potato	Squash, winter
Onion	Snap bean	
Pepper	Squash, summer	
Radish	Sweet corn	
Spinach	Tomato	

We find this approach is most beneficial for farmers with prior experience in managing irrigation within the targeted cropping system. Incorporating the soil moisture sensors allows them to fine-tune their irrigation practices, adapting to each season's specific environmental and crop conditions.

3. Using soil moisture sensors to prevent over-irrigation at a single event

When using drip irrigation, it's easy to over-irrigate during a single event, especially when crops require large amounts of water to recover from a drought stress. Over-irrigation in one irrigation event can cause water to drain beyond the root zone, which not only wastes water and nutrients but also raises environmental concerns. While it is possible to calculate the maximum irrigation duration based on the soil's water-holding capacity, these calculations can be complex and rely on multiple assumptions that may not always be accurate for specific conditions.

A more reliable method for optimizing irrigation duration is by using soil moisture sensors. To do this effectively, soil moisture status should be monitored beneath the emitter and at relatively shallow depths that respond to each irrigation event. Additionally, a separate sensor should be installed below or at bottom of the root zone. The estimated rooting depth of common crops is listed in Table 3.

The moisture sensor placed nearer the surface should respond to each irrigation event, confirming that irrigation is functioning properly. Meanwhile, soil moisture monitored by the deeper sensor should remain stable. If soil moisture at the bottom of the root zone increases after an irrigation event, it indicates that the irrigation duration is too long. In such cases, the irrigation volume should be reduced or the time between irrigations should increase.

Chapter 4. Irrigation Methods and Systems

Low-flow overhead and drip irrigation are the two most commonly used irrigation systems on small farms in Indiana. On farms growing a diverse range of crops, both systems are often utilized to meet the specific needs of each crop, and sometimes for the same crop at different stages of growth.

Low-Flow Overhead Irrigation

Most small farms opt to set up low-flow overhead systems, either hanging inside high tunnels (Figure 24) or using portable setups on the ground in both high tunnel and open-field condition (Figure 25). Low-flow overhead irrigation is commonly used for directly seeded cash crops, such as salad greens, spinach, carrots, and beets. It is also applied to cover crops and high-density plantings.

The low-flow overhead irrigation system typically involves multiple micro-sprinklers or wobblers installed on a quarter-inch feeder tube attached to a water supply line. The coverage areas and water volume can be adjusted by selecting different emitters, spacing them at various distances along the header line, and modifying their height from the ground. Many irrigation supply companies offer services to help farmers design customized systems and select emitters based on the designed coverage area.

Achieving uniform water application is essential for effective overhead irrigation. A non-uniform system

Figure 24. *A micro-sprinkler irrigation system hanging on the roof of a tunnel.*

Figure 25. *A micro-sprinkler system, positioned along the length of the bed and placed on the ground, is used to irrigate directly seeded and high-density crops.*

can lead to areas being under- or over-irrigated, complicating management and risking crop loss. To assess irrigation uniformity, place rain gauges or containers across the entire target area (Figure 26). After irrigating for a set period, measure the water collected at each location. It's recommended to evaluate uniformity after installing a new irrigation system and to conduct regular checks, as sprinklers or wobblers may become clogged, and system pressure can fluctuate over time.

A well-designed overhead irrigation system wets the entire planting area, ensuring even seed germination and eliminating the need for multiple drip tapes on the beds. In the summer, overhead irrigation may also help lower the temperature for cool-season crops.

Overhead irrigation has drawbacks: It encourages weed growth, is less water-efficient, and can create wet canopies that favor foliar diseases. Due to these pros and cons, for directly seeded high-value crops grown in high tunnels, farmers may use both overhead and drip irrigation methods for the same crop but at different stages. Overhead irrigation is employed during seed germination, with a switch to drip irrigation once plants have developed 4 or 5 leaves (Figure 27).

Drip Irrigation

Drip irrigation delivers water directly to the soil, ensuring high water-use efficiency and avoiding water contact with leaves, which significantly reduces the risk of foliar diseases. Most farms utilize drip tapes, which are available in a variety of thicknesses, emitter spacings, and flow rates to accommodate different needs. Drip tape is specifically engineered for agricultural use and differs from the soaker hoses commonly available for home gardens.

If drip tape is intended for reuse, choosing more durable tapes with thicker walls is advisable. The choice of emitter spacing should align with the crop in-row spacing. For crops spaced 2 feet or more apart, a 12-inch emitter spacing is commonly used, while closely spaced crops benefit from emitter spacings of 4 to 8 inches. When installing drip tape, it is recommended to position the emitters facing upward to reduce the risk of clogging. Additionally, placing drip tape under mulch improves water use efficiency and protects it from direct sunlight, which can shorten its lifespan.

Since drip tapes can become clogged over time, which is often difficult to detect, some farmers prefer to use individual emitters and emitter tubing attached to a water supply line for high-value, widely spaced crops such as tomatoes (Figure 28). This system is effective and can be reused for multiple seasons, but it significantly increases the initial material cost.

Figure 26. *Multiple rain gauges are placed in the tunnel to assess irrigation uniformity.*

Figure 27. *Overhead and drip irrigation are both used in the caterpillar tunnel at different crop growth stage.*

Figure 28. *The individual emitter and emitter tube attached to the water supply line is used in growing tomatoes.*

One drawback of drip irrigation is that it wets only the soil directly beneath the emitters (Figure 29). Depending on soil type, the maximum wetted area may extend 1 to 1.5 feet in diameter before water drains deeper into the soil profile. Due to the limited wetting areas, it is advisable to use multiple drip tapes per bed when planting multiple rows of crops on a single bed (Figure 27). This approach also benefits wider-spaced crops, such as tomatoes, peppers, and cucumbers, in high tunnels (Figure 30). This is because using multiple drip tapes ensures that a larger soil area is wetted, encouraging crops to develop a more extensive root system. Additionally, maintaining proper soil moisture is crucial for sustaining microbial activity, which plays a key role in converting soil amendments and organic matter into available nutrients that support plant growth.

***Figure 29.** Drip irrigation wets the soil area directly beneath the emitters.*

Usually, two drip tapes per bed are recommended, though some farmers may use up to four. When additional drip tapes are added to the bed, irrigation timing should be adjusted accordingly.

Irrigation Systems and Principles in Designing Irrigation Zones

Irrigation system design varies based on water sources, system scale, and management practices. However, regardless of scale, every system should include key components such as drip tapes or sprinklers, header pipes, flow meters, pressure regulators, pressure gauges, filters, and backflow preventer if fertilizer or chemical are injected. Additionally, understanding flow rate is fundamental for irrigation system design.

***Figure 30.** Multiple drip tapes are used on one tomato bed.*

The first step in this process is to determine the flow rate available from water source. If this information is not provided by the water supplier, farmers can measure it by timing how long it takes to fill a 5-gallon (or larger) container and then calculating the flow rate in gallons per minute (gpm) or gallons per hour (gph).

Flow rate information for micro-sprinklers, individual emitters and drip tape is provided by the manufacturer, expressed in gph per emitter or gpm per 100 feet at a certain pressure, e.g., 8 pounds per square inch (psi). To determine the total flow rate of an irrigation system, sum the flow rates of individual outputs (sprinklers, emitters, and drip tapes). It is crucial to ensure that the system's total flow rate does not exceed the available flow rate from the water source. If it does, the system should be divided into separate zones, with each zone irrigated at different times.

Understanding flow rate is also important for effective irrigation management. For example, assume the goal is to apply 100 gallons of water through drip tape to one bed in a week. Farmers can calculate how long irrigation should run to deliver the required amount of water based on the drip tape flow rate.

Micro-sprinklers typically operate at a pressure range of 20 to 30 pounds per square inch (psi), while drip tapes are designed to function within a range of 8 to 15 psi. Operating the system within these optimal pressure ranges ensures the water is applied evenly and at the desired flow rate. It is important to note that water pressure decreases as it travels through the system.

The irrigation system will include a "mainline" pipe or hose to deliver water from the source to each irrigation zone. Each zone will have a "sub-main" or "header" that provides water to the drip or micro-sprinkler for that zone. A flow meter, a pressure regulator and a pressure gauge are often incorporated into each zone of the irrigation system. The pressure regulator and pressure gauge ensure the system runs at consistent and optimal pressure ranges. The flow meter monitors the actual volume of water being applied to the system to ensure expected amount of water is applied to the system.

Filters are important to prevent clogging in micro-sprinklers and drip irrigation. Screen filters with a 150 to 200 mesh screen or comparable disc filters are suitable for city water or ground water. Sand filters are necessary for surface water, and a sand separator might also be necessary. A thorough discussion of filters is available in "*Filtration, Treatment, and Maintenance Considerations for Micro-Irrigation Systems*" from Virginia Tech. If acid, fertilizers, or pesticides will be injected into irrigation water, a backflow preventer between the injection point and water supply is necessary to prevent the material from contaminating the water source.

Detailed information about irrigation components can be found in specialized irrigation publications. "*Drip-irrigation Systems for Small Conventional Vegetable Farms and Organic Vegetable Farms*" by the University of Florida, IFAS Extension, offers an excellent overview of irrigation system designs and components.

Chapter 5. Irrigation Water Quality

Irrigation water quality can be evaluated based on its chemical, biological, and physical properties. It plays a critical role in vegetable production, influencing crop growth, soil conditions, equipment performance, and, in some situations, produce safety. Understanding these key water quality parameters and taking preventive measures, producers can avoid potential production issues.

Irrigation water quality should be assessed in the context of a given production system. This bulletin primarily addresses water quality for soil-based vegetable production. For hydroponic systems, where all plant nutrients are supplied through water, knowing the precise mineral content is crucial for determining any additional nutrients that need to be added. Hydroponic producers should follow guidelines specifically designed for these systems. This bulletin focuses on water quality parameters most likely to impact vegetable production on small farms in Indiana. Since most laboratories provide recommended ranges for each parameter in the reports, the desired ranges are not included in the bulletin.

Chemical Characteristics of Irrigation Water

The chemical characteristics of irrigation water encompass factors like pH, alkalinity, salinity, and the presence of specific minerals that can be of concern. Depending on water sources, attention should be placed on specific parameters.

pH and alkalinity

pH and alkalinity are related to irrigation water's acidity and basicity and potential impact on soil pH. pH is a measure of whether the water is acidic or basic. pH 7 is neutral, less than 7 is acidic, and greater than 7 is basic. pH of Indiana well water typically ranges between 6.5 to 8. High pH is common in groundwater in Indiana, which is usually associated with high alkalinity.

Alkalinity is the ability of water to neutralize acid. It is caused by bicarbonates, carbonates, and hydroxides dissolved in the water. Alkalinity is often reported as bicarbonate (HCO_3) in units of milligrams per liter (mg/l) or parts per million (ppm). For Indiana groundwater, alkalinity is closely related to water hardness. Both alkalinity and hardness are also reported as calcium carbonate ($CaCO_3$), in units of mg/l or ppm, or milliequivalents per liter (meq/l). Most Indiana groundwater is considered very hard. Localized areas of exceptionally hard water are found in northwestern Indiana in Lake County, south-central Indiana in Harrison and Washington counties, and northeastern Indiana in Adams County (Figure 31).

Although high pH and alkalinity are common issues in Indiana's groundwater, they are rarely a concern when surface water is used as the main water source for irrigation.

Problems caused by alkaline water

In open field production, high alkalinity in irrigation water can lead to problems such as emitter clogging and lime deposits on irrigation system components.

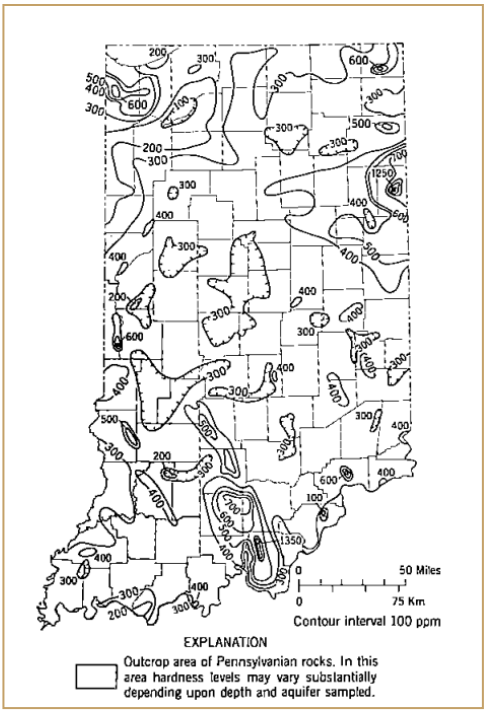

Figure 31. *Map of Indiana showing the distribution of water hardness of groundwater in parts per million (ppm) CaCO3. The map is adapted from Water Quality, Indiana Department of Natural Resources. https://www.in.gov/dnr/water/files/804_Water_Quality.pdf*

Figure 32. *Tomato yellow shoulder, a tomato fruit disorder typically occurs due to a deficiency in potassium, which might be caused by high levels of calcium and magnesium in the soil.*

In high tunnels, in addition to the lime deposits, the primary concern with alkaline irrigation water is the gradual increase in soil pH over time. This is because the alkalinity often results from dissolved calcium and/or magnesium carbonates, which are essentially dissolved lime. With each irrigation, a small amount of lime is added, accumulating over the season. For example, applying an inch of water per week for 15 weeks with water containing 450 ppm bicarbonate is equivalent to applying 85 lb. per acre per week of calcium carbonate lime, or more than half a ton per acre over the 15 weeks.

Sandy soils will experience pH increase more rapidly than heavier soils or soils with greater cation exchange capacity. Eventually, the soil pH can rise to a level where mineral nutrients become less available for plant uptake. Micronutrients such as manganese, iron, and zinc become less available at high pH levels, with manganese availability declining the most rapidly.

In addition to raising soil pH, using high-alkalinity water in covered structures over time may elevate soil levels of calcium and/or magnesium. While calcium and magnesium are essential plant nutrients, excessive levels can interfere with the uptake of potassium. Tomatoes require substantial amounts of potassium to produce high-quality fruit. If soil calcium and magnesium levels are excessively high relative to potassium, plants may not be able to absorb enough potassium, which increases the potential of developing yellow shoulder fruit (Figure 32).

Strategies for addressing alkaline water

For soil production in the open field, as natural rainfall contributes significantly to plant water needs, it is less likely that alkaline irrigation water would raise soil pH. However, if scale buildup or plugging is a problem, water may need to be acidified as discussed below.

In high tunnels, it is important to monitor soil pH annually and track changes over time to identify the trends. If irrigation water alkalinity is causing an increase in soil pH, consider using an alternative water source with lower alkalinity or mixing it with the less alkaline water. Surface water from ponds, streams, or rainwater collected in tanks generally has low alkalinity.

If needed, high alkalinity water can be treated by injecting acids such as sulfuric, phosphoric, or nitric acid. A calculator to determine the appropriate amount of acid to use can be found at *https://alkcalc.egromobi.com/*. For more detailed guidance, the article "*Adjusting alkalinity with acids*" by University of Massachusetts Extension provides comprehensive information on acid use for irrigation water. It is essential to use the correct amount of acid to avoid excessively lowering the pH, which can lead to other issues. Additionally, concentrated acids are hazardous, so proper safety precautions must be followed. In organic production, some farmers may choose to use citric acid, though its effectiveness and economic feasibility have not been fully tested.

Acid injection can also be used intermittently to prevent clogging and carbonate precipitation. For this purpose, it is recommended to inject enough acid to lower the

water pH below 4, then run the water for 30 minutes to an hour. Other water treatments, such as reverse osmosis, and potassium-based water softeners, can also be used to reduce alkalinity and lower pH. However, the cost-effectiveness of these systems has not been fully evaluated in soil production.

Most vegetable crops thrive in slightly acid soil with pH range of 6.0 to 6.5. If soil pH rises above 7, amendments such as elemental sulfur, and ammonium-based fertilizers can be used to lower it. For more detailed information on adjusting soil pH, refer to article "*Lowering Soil pH for Horticulture Crops*" by Purdue Extension.

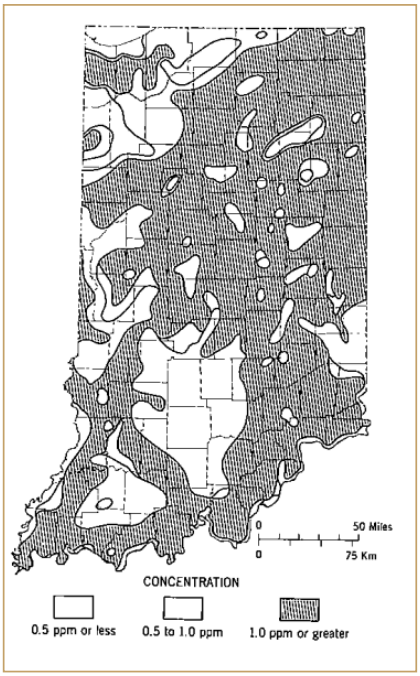

Figure 34. *Map of Indiana showing the general concentration of iron in ground water (ppm). The map is adapted from Water Quality, Indiana Department of Natural Resources. https://www.in.gov/dnr/water/files/804_Water_Quality.pdf*

Other chemical parameters

Iron – Groundwater in Indiana commonly has higher iron concentrations than the recommended maximum of 0.3 ppm (Figure 34). In aquifers, iron is in the ferrous form, dissolved in the water. When the water is brought to the surface and through an irrigation system, the pH and oxygen levels in the water increase, causing the iron to change to the insoluble ferric form. It forms orange or reddish precipitates that can plug emitters and look like a coat of rust on areas wet by the water (Figure 35). It can also promote growth of iron bacteria, which create slime and additional plugging.

To prevent plugging, a common strategy is to force the iron into the insoluble form and remove the precipitate

Figure 35. *Iron deposit on drip tape.*

before it reaches the emitters. It is also possible to use softeners to remove iron in water. Refer to article "*Management of iron in irrigation water*" by Rutgers Cooperative Research & Extension.

Salinity – Salinity refers to the total concentration of dissolved salts in water, typically measured using electrical conductivity in units of deci-Siemens per meter (dS/m) or millimhos per centimeter (mmho/cm). High soil salinity levels can negatively affect crop growth, but this issue usually stems from salt accumulation due to fertilizers or certain soil amendments. In Indiana, high salinity in irrigation water is rarely a concern.

Sodium – Sodium contributes to salinity and is reported in units of mg/l or ppm. While high sodium levels in untreated well water are uncommon in Indiana, it can still occur. Some aquifers naturally contain elevated sodium levels, and sodium can also enter wells through contamination from road salts or other sources. Common water softeners remove calcium and magnesium and replace them with sodium. It is not recommended to use sodium-softened water for irrigation.

Boron – Boron is a micronutrient essential for plant growth in very small quantities. However, excessive boron is toxic, and the range between sufficient and harmful amounts is narrow. Although high boron levels in well water are uncommon in Indiana, its presence should be monitored.

Chloride – Chloride levels are generally low in natural water sources in Indiana, but treated water may have higher concentrations. Chloride concentrations above 300 ppm are toxic to sensitive crops when absorbed through the roots. Additionally, overhead irrigation water with chloride levels above 175 ppm can cause toxicity in tomato leaves.

Manganese – Manganese levels in Indiana wells can exceed recommended levels. The primary concern for irrigation is that manganese can form a black precipitate, which may clog irrigation systems. However, manganese precipitates much more slowly than iron, making it less of an issue in irrigation water.

Sulfate – Sulfate concentrations can be high in Indiana well water, causing unpleasant taste and odor. However,

since sulfur is an essential plant nutrient, its presence in irrigation water is not problematic. Instead, sulfur from irrigation water can be factored into nutrient management plan.

Nitrate-nitrogen – Nitrate-nitrogen is often measured in irrigation water, with high concentrations typically indicating contamination from fertilizer runoff, leaching, sewage, or manure storage. Concentrations above 10 ppm in drinking water pose significant health risks. However, since nitrogen is a key plant nutrient, nitrate-nitrogen in irrigation water is not a problem for plant growth. High levels can be incorporated into the overall nutrient management plans.

Biological Characteristics of Irrigation Water

Biological concerns include microbes — bacteria, fungi and others — and algae. Slime-producing iron bacteria were discussed above. There are similar sulfur bacteria that produce a white slime and can also be managed with chlorine.

Plant pathogens can occasionally be found in surface water. Pythium and phytophthora are two fungi like organisms — water molds — with spores adapted to moving around in water. Phytophthora has been found in surface waters, such as streams. The spores move with runoff from a field into retention ponds and streams, which may later be used for irrigation, moving the pathogen to another field. Plant diagnostic labs don't routinely test irrigation water for plant pathogens, but they can help diagnose disease problems when you suspect a link to irrigation water quality. For help, contact *Purdue Plant and Pest Diagnostic Lab*.

Human pathogens in irrigation water are a food safety concern. Good Agricultural Practices (GAPs) for food safety include guidelines for assessing and reducing risk in irrigation systems, water sources, and irrigation practices. Producers covered under the federal Produce Safety Rule (PSR) of the Food Safety Modernization Act (FSMA) are required to assess agricultural water for potential contamination risks at least annually, which can include testing irrigation water for generic *E. coli*. In addition, growers should assess the entire irrigation system for risk and implement corrective actions if necessary. It is recommended that all producers of fresh produce follow these guidelines. Producers who are required by their buyers to pass a third-party GAPs audit will likely need to test water as part of their food safety protocol. Learn more at *Safe Produce Indiana*, including how to determine if you are covered under the PSR.

A key approach to dealing with human pathogenic bacteria is to, when possible, understand relative risk of various practices, choose less risky practices, and use best practices to mitigate those risks. The source of the water is an important factor in risk. Municipal and other public water systems maintain water at standards for drinking and so are at very low risk for contamination with human pathogens. Private wells have a medium risk because they can become contaminated from septic systems, wildlife, or manure if not maintained properly, and are not tested as frequently. Ponds, streams, rivers and other surface water carry the most risk, as they are the most likely to contain pathogens.

The method of water application also influences risk of contaminating produce. Practices that allow irrigation water to contact the edible part of the crop are the riskiest: sprinkler irrigation of tomatoes, or for root crops, any irrigation that wets the soil around the edible root. Drip irrigation with the drip tape placed underneath a mulch or buried in the soil would have a low risk for a tomato crop.

Physical Characteristics of Irrigation Water

Water sediments

Irrigation water from a pond, stream, or cistern may contain algae or sediment that can plug or damage equipment. Algaecides containing chlorine or copper sulfate can be used in some situations. Filters are critical for catching sediment. Sand filters are commonly used for this purpose. A pair of containers filled with sand catches the sediment. Periodically the filters must be back-flushed. Sand filters are available from irrigation supply companies, or can be made on the farm as described in the publication "*Low-Cost Irrigation Sand Filter*" by the University of Vermont Extension.

Water temperatures

The temperature of irrigation water can significantly impact seed germination and plant growth. During the summer, using cooler water may enhance the germination of heat-sensitive seeds such as spinach and lettuce. Surface water may not be cool enough to make a significant difference, so if groundwater is readily available, that would be a better choice for cooling the soil. In later fall, winter and spring, when soil temperatures are low, irrigation with warm water can help raise soil temperatures, promoting faster plant growth. This is especially beneficial for warm-season crops, such as cucumbers, grown in the spring.

Irrigation Water Tests

Chemistry tests

Municipal and public water supplies are required to test water regularly and provide results to users. Contact a water department to request the results. The standard

report mailed to customers may not include information on all of the chemistry discussed above.

Several commercial laboratories offer testing services for private well water or surface water to assess irrigation suitability. The followings are examples. This is not an all-inclusive list.

- *A&L Great Lakes*
- *Brookside Labs*
- *Waters Ag Labs*

In addition to a comprehensive irrigation water suitability test by a commercial lab, on-farm tools are available for testing pH, electrical conductivity (EC), alkalinity (or hardness), and nitrate-nitrogen. The least expensive are color-based systems, such as litmus paper for pH, or alkalinity or nitrate test strips. While these methods are less precise, they offer quick and easy results.

For growers who frequently mix soluble fertilizer, inject acid into irrigation system, or regularly monitor growing medium pH or electrical conductivity, having a reliable pH and EC meter is extremely useful. These meters can also be used to test irrigation water. New technologies that integrate with smartphones are likely to become available, offering even more convenient and capable testing options.

Biological tests

Testing water for food safety purposes involves testing for the indicator bacteria generic *E. coli*. If generic *E. coli* is present, it is likely that the water has been contaminated with fecal matter, and human pathogens are more likely to be present. If indicator bacteria are present in high numbers the water must be treated before use, or applied in a way that it will not contact the edible portion of produce normally eaten raw.

Refer to the publication "*Indiana Water Testing Labs*" by Safe Produce Indiana for a complete list of labs that perform the test for generic *E. coli.* If you wish to use the water source for drinking, hand-washing or washing produce as well as irrigation, a presence/absence test is adequate because zero detectable *E. coli* is permitted in water used for those purposes. If you need to use the water source only for irrigation, choose a lab that offers quantification. Be sure to follow closely the instructions the lab will send for collecting the sample and sending it in for testing.

Frequency of irrigation water testing

The chemistry of well water can change over time. An annual test before the irrigation season would allow timely actions before the season starts. If annual tests show little to no variation, it may be reasonable to extend the time between tests, provided there are no changes (e.g., droughts or increased aquifer usage) that could impact water quality. For food safety purposes, it is highly recommended that water testing be conducted at least annually if the grower is held to no other regulatory or buyer-driven requirements. Be sure to consult specific food safety regulations for detailed water testing requirements.

For more information on irrigation water quality, the *Clean Water*[3] website offers a wealth of resources covering this topic.

Chapter 6. Mulches and Water Management

Using mulch to maintain soil moisture is highly effective and widely adopted on small farms. In addition to conserving moisture, mulch plays a crucial role in controlling weeds and reducing soil erosion. Additionally, natural mulches contribute to soil fertility over time as they decompose.

While traditional vegetable farms often rely on plastic mulches, small farmers tend to use a variety of materials tailored to their specific needs and availability (Figure 36). These include synthetic options, such as plastic mulch and landscape fabric, as well as natural materials, such as straw, woodchips, compost, leaves and wool. Biodegradable materials, including paper, cardboard, and burlap bags, are also utilized on small farms.

Figure 36. *Various mulch materials are used at small farms.*

For a comprehensive overview of different types of mulches, their applications, and their effects on soil health, refer to the "'*Mulches for Small Farms and Gardens Overview*" by NRCS. This bulletin mainly focuses on the relationships between common mulches and water management.

As mentioned earlier, plants with extensive root systems, like tomatoes and melons, often extend their roots beyond the planting beds. Applying mulch to both planting beds and pathways helps retain soil moisture over a larger area, supporting root expansion and benefiting soil microorganisms, which enhances overall soil health. The effectiveness of mulch in retaining soil moisture, influencing soil temperature, and impacting soil health depends on the type used.

Black plastic mulch raises soil temperatures, making it particularly useful in the spring for growing warm-season crops. In contrast, white plastic mulch cools soil, making it beneficial for crops transplanted after the soil has warmed. Farmers may use white plastic instead of black plastic for summer-planted tomato and pepper to prevent heat damage to young seedlings, particularly around the planting holes.

Plastic mulch is impermeable to water, and when combined with drip irrigation it significantly enhances irrigation efficiency. However, when plastic mulch is used with overhead irrigation or relies primarily on natural precipitation, the soil beneath it can become drier than adjacent areas. This is because roots absorb the moisture, and the plastic blocks water from reaching the soil underneath the plastic. Soil in the bed will get water only after heavier rain or irrigation leads to water infiltration into the bed from the sides and from the water that enters the planting holes. While drier conditions under plastic mulch can be advantageous in excessively wet situations, they negatively impact crops when irrigation and rainfall are limited. A drawback of using plastic mulch is the lack of options for reuse or recycling if it is not biodegradable.

Compost made from leaves and other plant materials, or food wastes, is often applied as a mulch on top of the soil. Typically, a 2-inch layer of compost is used, which effectively suppresses weeds and significantly improves soil fertility. Some farmers may plant seeds directly into the compost mulch. However, as the dark color of the compost can cause the surface to dry quickly, special attention must be given to maintaining adequate moisture for seed germination. Additionally, if the compost hasn't been thoroughly watered, it may have high salts, which can inhibit seed germination. Compost made from plant- or animal-based materials can lead to excessive phosphorus buildup in the soil, potentially causing nutrient imbalances. Regular soil tests should be conducted to monitor these changes.

Woodchips are highly effective at maintaining soil moisture, and when applied 3-4 inches deep, they often provide better weed control compared to straw mulch of the same depth. However, woodchips have drawbacks when used as mulch in vegetable planting rows. In excessively wet conditions, the soil beneath woodchips can become saturated for extended periods, which can hinder plant growth. If this saturation occurs early in the season, it can damage roots, making recovery difficult and potentially affecting growth and yield for the remainder of the season. As a result, woodchips are generally not recommended for vegetable planting beds in open fields exposed to natural rainfall in Indiana, though they are an excellent choice for pathways. Additionally, when mulch materials with high carbon content are incorporated into the soil, additional nitrogen needs to be applied to support immediate crop production.

When using organic mulch with transplanted plants, ensure the mulch does not come into direct contact with the plant stems. Direct contact can increase the risk of diseases occurred around the stem, which may lead to plant death.

Suggested Resources

Chapter 1

Midwest Vegetable Production Guide. https://mwveguide.org/guide

Chapter 2

Water Drainage at High Tunnel Improved. Missouri State University. https://blogs.missouristate.edu/fruitexperimentstation/2017/11/09/water-drainage-at-high-tunnel-improved/

Indiana High Tunnel Handbook. Purdue University Extension. https://www.extension.purdue.edu/extmedia/HO/HO-296.pdf

Web Soil Survey. USDA, NRCS. https://websoilsurvey.nrcs.usda.gov/app/HomePage.htm?TARGET_APP=Web_Soil_Survey_application_ffsdbb3dq5ewitkh0ko13l5w

Reference Evapotranspiration Forecasts Across Indiana. Vegetable Crops Hotline. https://vegcropshotline.org/article/reference-evapotranspiration-forecasts-across-indiana/

Monitoring Potential Evapotranspiration Across Indiana. Vegetable Crops Hotline. https://vegcropshotline.org/article/monitoring-potential-evapotranspiration-across-indiana/

Crop Evapotranspiration- Guidelines for Computing Crop Water Requirements – FAO Irrigation and Drainage paper 56. https://www.fao.org/4/x0490e/x0490e00.htm#Contents

Irrigation of Field Crops in Indiana. Purdue University Extension. https://earchives.lib.purdue.edu/digital/collection/AESmimeoID/id/1437/rec/115

Soil Texture Calculator. USDA, NRCS. https://www.nrcs.usda.gov/resources/education-and-teaching-materials/soil-texture-calculator

Root Development of Vegetable Crops. https://soilandhealth.org/wp-content/uploads/01aglibrary/010137veg.roots/010137toc.html

Chapter 3

Estimating Soil Moisture by Feel and Appearance. USDA, NRCS. https://www.wcc.nrcs.usda.gov/ftpref/wntsc/waterMgt/irrigation/EstimatingSoilMoisture.pdf

Improving Irrigation Water Use Efficiency: Using Soil Moisture Sensors. Michigan State University Extension. https://www.egr.msu.edu/bae/water/irrigation/sites/default/files/content/E3445_Improving%20Irrigation%20Water%20Use.pdf

Principles and Practices of Irrigation Management for Vegetables. University of Florida, IFAS Extension. https://edis.ifas.ufl.edu/publication/CV107

Chapter 4

Filtration, Treatment, and Maintenance Considerations for Micro-Irrigation Systems. Virginia Cooperative Extension. https://www.pubs.ext.vt.edu/442/442-757/442-757.html

Drip-Irrigation Systems for Small Conventional Vegetable Farms and Organic Vegetable Farms. University of Florida, IFAS Extension. https://edis.ifas.ufl.edu/publication/HS388

Chapter 5

Water Quality. Indiana Department of Natural Resources. https://www.in.gov/dnr/water/files/804_Water_Quality.pdf

ALKCALC. https://alkcalc.egromobi.com/

Adjusting Alkalinity with Acids. University of Massachusetts Extension. https://ag.umass.edu/greenhouse-floriculture/fact-sheets/adjusting-alkalinity-with-acids

Lowering Soil pH for Horticulture Crops. Purdue University Extension. https://www.extension.purdue.edu/extmedia/ho/ho-241-w.pdf

Management of Iron in Irrigation Water. Rutgers Cooperative Research & Extension. https://njaes.rutgers.edu/fs516/

Purdue Plant and Pest Diagnostic Lab. https://ag.purdue.edu/department/btny/ppdl/

Safe Produce Indiana. https://ag.purdue.edu/department/extension/safeproduce/

Low-Cost Irrigation Sand Filter. University of Vermont Extension. https://www.uvm.edu/sites/default/files/The-Center-for-Sustainable-Agriculture/resources/SandFilterHowToLarge.pdf

A&L Great Lakes Laboratories. https://algreatlakes.com/
Brookside Labs. https://www.blinc.com/

Waters Agricultural Laboratories. https://watersag.com/

Indiana Water Testing Labs. Safe Produce Indiana. https://ag.purdue.edu/department/extension/safeproduce/_docs/indiana-water-testing-lab-guide-6-9-2021.pdf

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Mulches for Small Farms and Gardens Overview. USDA, NRCS. https://static1.squarespace.com/static/601099353a53016c03aa44c5/t/66e1b87a2665cd471fc36c4d/1726068858987/484+IN+PO+Mulching+for+Small+Farms+and+Gardens+2024.pdf

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All photos except Figure 23 by Wenjing Guan and Elizabeth Maynard

HO-122

University of Kentucky
College of Agriculture, Food and Environment
Cooperative Extension Service

Go with the Flow

Simple Calculations for Small Drip Irrigation Systems

Brent Rowell, Department of Horticulture

While drip irrigation is relatively easy, information about it is often more complicated and confusing than it needs to be. Well-meaning professors and engineers use terms like "head" and "flow rate" without explaining exactly what they mean and how they are used. And it's often difficult to get help planning a small farm system in states without large irrigated acreages and irrigation traditions. The purpose of this bulletin is to help farmers understand the simple calculations involved in designing a small drip irrigation system.

We will discuss flow rates, pressures, pipe sizes, amount of drip tape, and pump size required for an acre of peppers, although it would be about the same for most vegetables, flowers, or other high-value horticultural crops. This example will help you better understand how to figure out the optimum layout of a small drip irrigation system.

Most of the calculations shown here are unnecessary if you know how to use tables and charts provided by irrigation supply companies and manufacturers; this discussion should help you better understand how to use those resources. *Don't be afraid of the math*—it's all simple arithmetic.

Peppers are usually grown on black plastic mulch with two rows per bed in beds 6 ft apart. A single drip line is used in the center of each bed between the two rows of peppers (drip lines are therefore also 6 ft apart). Let's say our field is 200 ft long with 36 beds or 216 ft wide (36 x 6 ft = 216 ft). We will irrigate from a pond which is below the level of our field (**Figure 1**).

The field is flat but is 15 ft above the pump; the pump is on a bank that is 8 ft above the pond. The pump is also 300 ft from the pepper field so our delivery or main line will need to be at least 300 ft long. We will also need a secondary pipe (called a submain) to run across the edge (or sometimes in the center) of the pepper field. The drip lines (also called drip "tape") will be connected to this submain line. Since our field is 216 ft wide we will need at least 216 ft of pipe for the submain.

Total System Flow

Each of our 36 rows is 200 ft long so we will need about 36 x 200 ft = 7,200 ft of drip tape. From the irrigation supply catalog or from the label on the roll of drip tape (**Figure 2**) we see that the flow rate of our tape is 0.5 gallons per minute (gpm) for each 100 ft of tape when the system is pressurized at 8 psi. So to determine our total flow in this one-acre plot through 7,200 ft of drip tape, first divide 7,200 ft by 100 = 72 and multiply the result by 0.5 gpm (72 x 0.5 gpm = 36

psi = pounds per square inch; normal pressure for drip tape is in the 8-15 psi range. Some tapes will function at pressures as low as 1-2 psi with gravity systems although flow will be much reduced so that longer irrigation times are required.

Figure 2. Flow rate in gallons per minute (gpm) per 100 ft of drip tape is indicated on the label attached to each roll of drip tape.

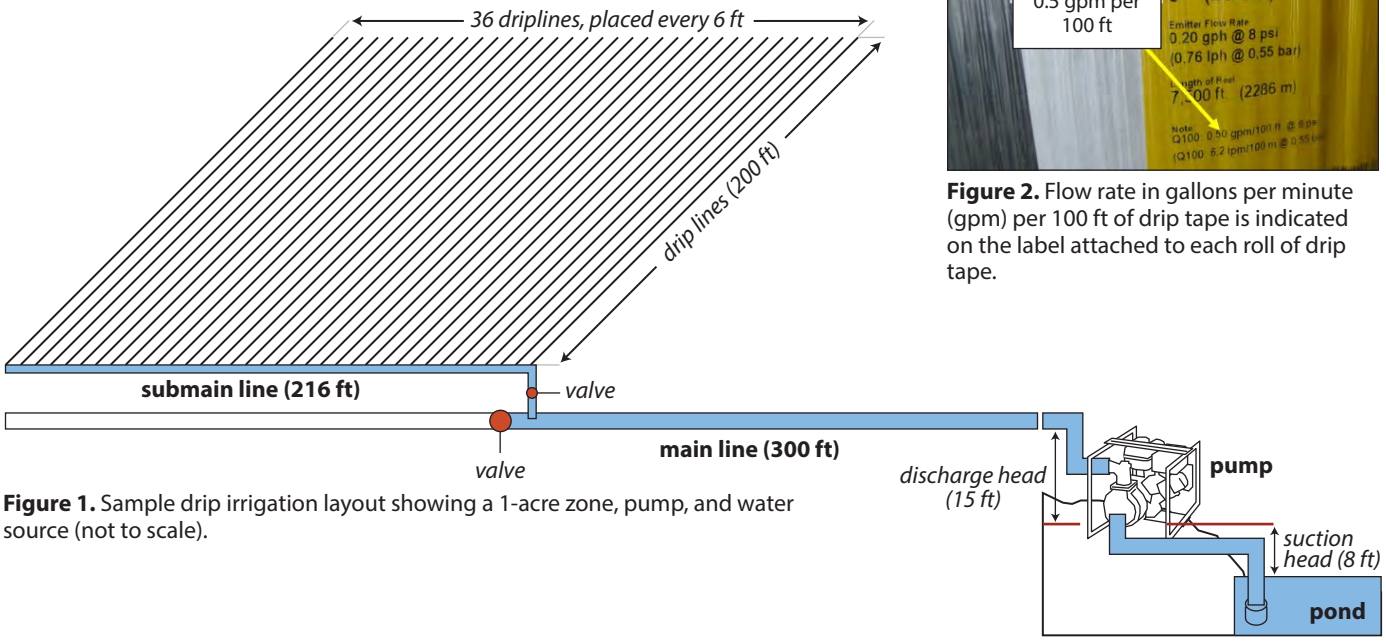


Figure 1. Sample drip irrigation layout showing a 1-acre zone, pump, and water source (not to scale).

gpm). To calculate gallons per hour (gph) simply multiply gpm by 60 minutes (36 gpm x 60 = 2,160 gph). Our pump will need to supply this much water at 10-15 psi pressure to the field's submain.

Pump Pressure and Flow

In pump and irrigation lingo, the term "head" is often used to indicate the maximum height which a pump can push water (**Figure 3a**). It's also used interchangeably with pressure or pressure losses in a system (i.e., "head losses"). Pressure can be expressed either as pounds per square inch (psi) or as the vertical height of a water column in feet:

2.31 ft height of elevated water = 1 psi pressure

Companies usually provide specifications that tell you how powerful a pump is. This is not only in terms of the motor's horsepower but the capacity of the pump to move water. Its pumping power is usually described in terms of maximum pressure (head) and flow rate. The *maximum head* or pressure of the pump is the maximum height to which it will pump water. If a pump's maximum head is 115 ft, it means that all of the pump's energy is used to pump water up to that height, and at that height it can push water no further, so its flow is zero (**Figure 3a**). On the other hand, a pump's *maximum flow rate* is the amount of water it discharges at its outlet (level surface, no head, **Figure 3b**). A pump with this information on its label is shown in **Figure 4**.

But in order to select the right pump, we need to know about its performance in between these two extremes. We need to know its flow rate at different pressures (or heads). Most pump makers provide this in the form of a table or graph. **Figure 5**, for example, is the performance curve for the pump shown in **Figure 4**.

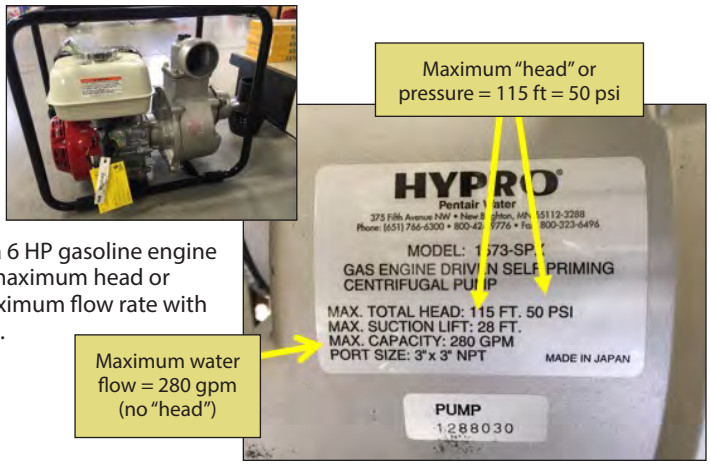


Figure 4. Label on a 6 HP gasoline engine pump showing its maximum head or pressure and its maximum flow rate with no head or pressure.

The curve (blue line) shows that the pump's flow (horizontal axis) decreases as it is required to push water upwards to different heights (vertical axis). Flow decreases in the same way if the pump must move water through the restrictions of an irrigation system like pipes, pipe fittings, valves, filters, and injectors. This relationship is different for different pumps; **Figure 5** is just one example.

If you know, for example, that your irrigation setup requires a flow rate of 50 gallons per minute at 40 psi, this pump would be suitable as it will produce a flow of 50 gpm at 45 psi (follow the red

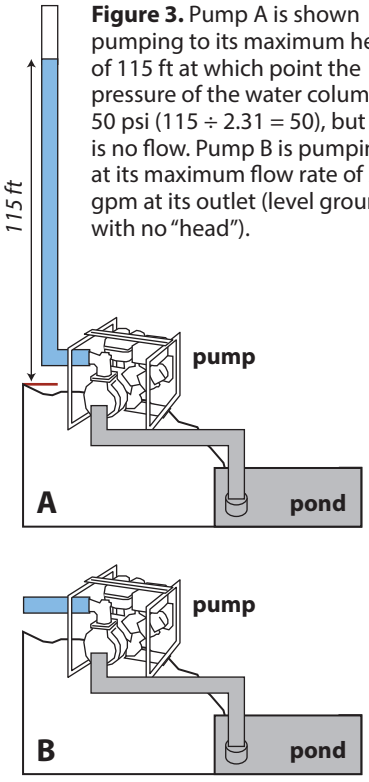
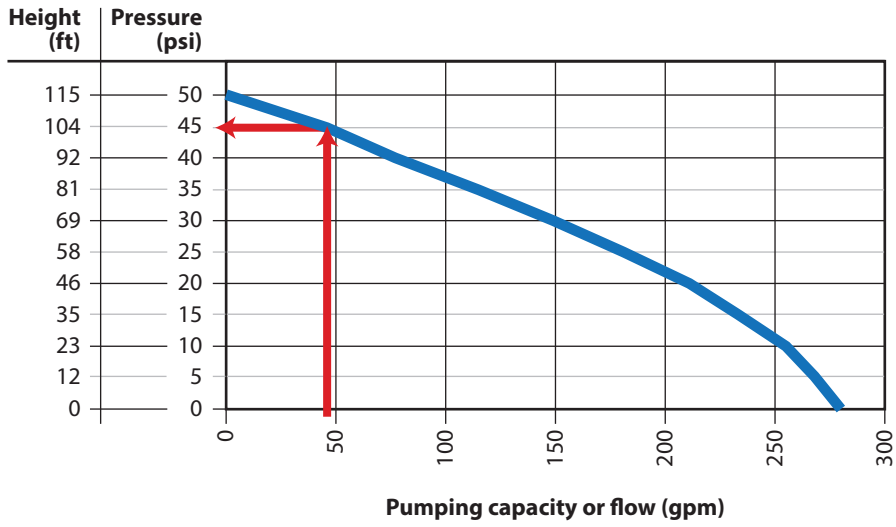


Figure 3. Pump A is shown pumping to its maximum height of 115 ft at which point the pressure of the water column is 50 psi (115 ÷ 2.31 = 50), but there is no flow. Pump B is pumping at its maximum flow rate of 280 gpm at its outlet (level ground with no "head").

Figure 5. Sample of a pump's performance curve. The blue line shows how much water this particular pump can move to a given height or "head". Head is expressed as height of a water column in feet or as pressure in psi. Note that the pump's flow rate decreases as it is required to pump to greater heights or as the head or pressure increases.



arrows in **Figure 5**). Excess pressure can be reduced at the submain with a pressure reducer.

System Pressure

But how do we know how much total water pressure is required for our acre of peppers? Pressure can be estimated for our example in **Figure 1**. First of all we require pressure to push up the 15 ft to the field from the pump and to pull water up from 8 ft below the pump. We add this "discharge head" and "suction head" together so that:

	ft				psi
discharge head:	15 ft	÷	2.31	=	6.49
suction head:	8 ft	÷	2.31	=	3.46
total:				=	9.95

Most common suction pumps will not lift water more than 23 ft from the water's surface. This suction head is further limited by things such as check valves and filters between the water source and pump.

Next we add our system operating pressure required in the field (at the submain), which for drip should be around 10-15 psi:

9.95 psi (calculated above) + 15 psi = 25 psi

To this we must add pressure that will be needed to overcome friction through pipes, filters, injectors, etc. This type of information is often provided by the manufacturer or can be found in irrigation supply catalogs.

In our example we will use 300 ft of 2-inch layflat for the main line to the field. Knowing that our system flow rate is 36 gpm, we can use **Table 1** to find the friction loss for each 100 feet of this pipe.[1] Our flow rate is between 30 and 40 gpm, so we can estimate that our loss is a little less than the 1.1 psi indicated for 40 gpm flow in the table. Since the pressure loss is about 1 psi per 100 ft (blue box in the table), the loss for 300 ft of 2-inch layflat will be:

1 psi x (300 ÷ 100) or 1 x 3 = 3 psi

Table 1. Pressure losses (in psi) from friction in different diameters of layflat pipe (per 100 feet) at different flow rates.

Flow Rate (gpm)	Pipe Diameter					
	1.5"	2"	2.5"	3"	4"	6"
20	1.2					
30	2.4					
40	5.1	1.1				
50	6					
60		2.4	1.4			
80		4.1	1.9	1		
90	17					
100		6	2.8	1.2		
120				1.8		
140				2.2		
160				2.6	0.6	
180				3.3	0.7	
200		22	7		0.8	
220					1	
250				5		
280					1.4	0.2
300					1.6	0.2
350			22			
380						0.4
420						0.5
460						0.6
500					4	0.7
580				22		0.9
620						1

Courtesy Rain-Flo Irrigation, East Earl, PA

Although we could also use 2-inch layflat for the 216-ft-long submain in **Figure 1**, we instead chose to use 1½-inch layflat. Since our flow rate of 36 gpm lies between 30 and 40 gpm in **Table 1** (red box), our friction loss in the pipe is between 2.4 and 5.1 psi per 100 ft. Since the flow is closer to 40 gpm we'll use 4 psi as our loss per 100 feet of pipe; our total friction loss in 216 ft of 1½ in. layflat will be:

4 psi x (216 ÷ 100)
or
4 x 2.16 = 8.64 psi (about 9 psi)

Since water is being removed through each of the drip lines in the submain, a good rule of thumb is to divide our submain loss by 3 to obtain a more accurate estimate (9 psi ÷ 3 = 3 psi). We will now add this 3 psi to the 3 psi loss from the 2-inch main line above to the total. We will also need to include losses of 10 psi from the filter (as stated by the manufacturer) and 5 psi from a fertilizer injector.[2]

Now our total "head" or pressure requirement is:

	psi	
	25	*operating + discharge + suction head*
+	3	*loss from 300 ft of 2-inch layflat main*
+	3	*loss from 216 ft of 1½-inch layflat submain*
+	10	*filter*
+	5	*injector*
=	**46**	*total head or pressure required from the pump*

This 46 psi can be converted back to height of a water column by multiplying by 2.31, so

46 psi x 2.31 = 106 ft

[1] This table is only for layflat pipe; other types of delivery pipe like black oval hose or PVC will have different friction loss charts.

[2] Check with the manufacturer to find out the pressure losses for your filter and fertilizer injector.

At this point we can use the 46 psi (106 ft) pressure plus our system flow rate of 36 gpm to help select a pump based on dealer recommendations, catalog specifications and pump performance curves like the one in **Figure 5**. This same information can also be used to determine the size of pump we need using the following formula:

HP (horsepower)
= (flow x total head) ÷ (3,969 x 0.6)*

* This formula uses an assumed generic pump efficiency factor of 60%.

So for our example:

(36 gpm x 106 ft) ÷ (3,960 x 0.6)
= 3,816 ÷ 2,376
= **1.6 HP**

To allow for future crop expansion we might want to double this size or at least increase its power by 25% to a 2 HP pump (1.6 HP x 1.25 = 2 HP) or even a 4-5 HP pump. A safer approach is to discuss your needs with a knowledgeable dealer who has experience with pumps and irrigation who can also help you estimate the system flow rate and total head as in the example above. Keep in mind that horsepower is not as important as a pump's overall performance as indicated in graphs like the one in **Figure 5**. Beware of online or other pump purchases based on horsepower or flow rate without knowing the pump's performance characteristics.

This does not mean that this 2 HP pump is limited to an acre, but that you will only be able to irrigate an acre at a time; more one-acre zones could be added.

A "zone" is a section of the field or farm that you will irrigate all at one time, like the acre of peppers discussed in this bulletin. It is usually separated from other zones with valves as shown in **Figure 1**. Larger zone sizes will require larger diameter mains and submains and more pumping power.

Pipe Size Matters

In the above example we calculated friction losses in 1½-inch layflat pipe. Pipe size has a drastic effect on friction losses; the larger the pipe diameter, the lower the friction losses inside the pipe at any given flow rate. Even a small increase in pipe diameter can reduce friction and increase flow, especially in low pressure gravity-fed systems.

You may (or may not) remember from high school math that the area of a circle is equal to πr^2 or 3.1416 x the radius of a circle squared. When this is applied to pipes it becomes clear that doubling the pipe diameter more than doubles the area inside for water to flow. Doubling a pipe size from 1½-inch to 3-inch diameter, for example, results in four times the area for water to flow inside the pipe (**Figure 6**).

If you already know your system flow rate in gallons per minute you can also use **Table 2** to determine the optimum pipe size for your main or submains. If your system flow rate is 36 gpm, for example, the optimum pipe size would be 1½ inches (inside diameter).

But I already have a pump…

How do I know my optimum zone size?

Another approach to determining the optimum size of your drip layout for the most uniform water and fertilizer application is to measure the flow rate of the system you already have. First set up your pump and the other components of your system (main valve, filter, injector, main line, etc.). Work with an assistant to measure the flow rate at the end of a submain without the driplines attached.

Have the assistant open the valve(s) and use a watch or stopwatch to measure the time it takes to fill a 5-gallon bucket, 55-gallon drum, etc. If it takes 10 seconds to fill a 5-gal bucket, for example, your flow rate at that point in the system is 5 gal ÷ 0.17 min = 29.4 gallons per minute.[3]

This flow rate can now be used to determine your *maximum zone size.* Each zone is separated by valves (red dots in **Figure 1**) so that it can be irrigated separately. If we are using the drip tape described in the pepper example with a flow rate of 0.5 gpm per 100 ft, we can estimate the maximum footage of drip tape that can be used for each zone. Simply divide the flow rate at the submain (29.4 gpm, calculated above) by the flow rate of the drip tape (0.5 gpm per 100 ft):

(29.4 gpm ÷ 0.5 gpm) x 100 ft
= 58.8 x 100 ft
= 5,880 ft of drip tape

This means you should not use more than 5,880 total feet of this particular drip tape in a zone and assumes your pump provides 10-15 psi pressure to the submain. If your rows are each 200 ft long, for example, you could have up to 29 rows of drip in a zone (5,880 ft ÷ 200 ft = 29.4). To be on the safe side you could also reduce this zone size by 25%, so 29 rows x 0.75 = 21 two-hundred-foot rows.

You can add more zones of the same size as long as they can be irrigated separately using valves. Keep in mind that additional zones may require a longer main and additional submains which in turn will require additional pressure and flow. These can be added to your total head calculations like those on Page 3.

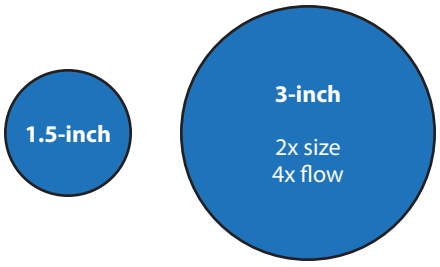


Figure 6. Doubling the pipe diameter results in four times the area inside the pipe and four times the flow.

Table 2. Optimum (most economical with minimal friction losses) pipe sizes for flow rates from 5 to 120 gallons per minute.

Flow (gpm)	Pipe diameter* (inches)
5	½
10	¾
15	1
25	1¼
35	1½
55	2
85	2½
120	3

*Inside diameter of schedule 40 PVC pipe with flow not exceeding a velocity of 5 ft/second.

[3] 10 seconds ÷ 60 sec = 0.17 minutes

Using Larger Zones

If you want to irrigate larger areas at one time of up to say, 3 acres, then you need to know the total flow rate for 3 acres. An acre is 43,560 square feet or roughly 208.7 ft x 208.7 ft. If your row-to-row spacing is 6 ft you will have 208.7 ÷ 6 = 34.7 or 34 rows. Since the 34 rows are 208.7 ft long you will have a total length of drip tape in the field equal to 34 x 208.7 ft = 7,096 ft.

In this example we will use the same drip tape with a flow rate of 0.5 gpm per 100 ft. So to calculate the total flow through 7,096 ft of drip tape, first divide 7,096 by 100 = 70.96. Multiply this result by the flow rate: 70.96 x 0.5 = 35.5 gpm for the whole acre. For three acres that is 35.5 gpm x 3 = 106.5 gpm. For a three-acre zone your pump will need to supply 106 gpm with pressures of 10-15 psi to the submain.

An easier way to determine the total length of drip tape required is to divide the number of square feet in an acre (43,560 sq. ft) by the spacing in feet between drip lines. So in our example 43,560 ÷ 6 ft = 7,260 ft of drip tape. Fortunately, you don't need to do these calculations as they have been done for you in charts such as **Table 3** (available from irrigation-supply dealers). The red arrows indicate the closest drip tape flow rate to our example (0.45 gpm per 100 ft) and a row-to-row spacing of 6 ft (72 in.). The total flow for an acre is where the two arrows meet at 33 gpm per acre which is slightly less than the 35.5 gpm calculated above.

While this publication doesn't contain all you need to know to set up a small drip system, it should be enough to get you started and help you understand more about flow rates, pressures, pumps, pipes, and plot sizes. See also:

- The UK Center for Crop Diversification's Water Resources web page, http://www.uky.edu/ccd/water
- UK publication HO-120: *Off the Grid: Ultra-low Pressure Drip Irrigation and Rainwater Catchment for Small Plots and High Tunnels,* http://www2.ca.uky.edu/agcomm/pubs/HO/HO120/HO120.pdf

Table 3. Flow rates in gallons per minute (gpm) per acre for drip tape. To use this table you will need to know your drip tape's flow rate per 100 ft and its emitter spacing, which are provided by the manufacturer (see **Figure 2**).

Select your row spacing in the left column to determine the amount of drip tape required per acre and its total flow rate per acre.

Row spacing (inch)	Drip tape/acre (ft)	Drip tape emitter spacing (inch)						
		8"	8"	12"	12"	16"	16"	24"
		Drip tape flow rate (gpm per 100 ft)						
		0.67	0.34	0.45	0.22	0.34	0.17	0.28
30	17,424	117	59	78	38	59	30	49
32	16,335	109	56	74	36	56	28	46
34	15,374	103	52	69	34	52	26	43
36 (3 ft)	14,520	97	49	65	32	49	25	41
38	13,756	92	47	62	30	47	23	39
40	13,068	88	44	59	29	44	22	37
42	12,446	83	42	56	27	42	21	35
44	11,880	80	40	53	26	40	20	33
46	11,363	76	39	51	25	39	19	32
48 (4 ft)	10,890	73	37	49	24	37	19	30
50	10,454	70	36	47	23	36	18	29
52	10,052	67	34	45	22	34	17	28
54	9,680	65	33	44	21	33	16	27
56	9,334	63	32	42	21	32	16	26
58	9,012	60	31	41	20	31	15	25
60 (5 ft)	8,712	58	30	39	19	30	15	24
62	8,431	56	29	38	19	29	14	24
64	8,168	55	28	37	18	28	14	23
66	7,920	53	27	36	17	27	13	22
68	7,687	52	26	35	17	26	13	22
70	7,467	50	25	34	16	25	13	21
72 (6 ft)	7,260	49	25	33	16	25	12	20
74	7,064	47	24	32	16	24	12	20
76	6,878	46	23	31	15	23	12	19
78	6,702	45	23	30	15	23	11	19
80	6,534	44	22	29	14	22	11	18
82	6,375	43	22	29	14	22	11	18
84 (7 ft)	6,223	42	21	28	14	21	11	17
86	6,078	41	21	27	13	21	10	17
88	5,940	40	20	27	13	20	10	17
90	5,808	39	20	26	13	20	10	16
92	5,682	38	19	26	13	19	10	16
94	5,561	37	19	25	12	19	9	16
96 (8 ft)	5,445	36	19	25	12	19	9	15
98	5,334	36	18	24	12	18	9	15
100	5,227	35	18	24	11	18	9	15

Courtesy Rain-Flo Irrigation, East Earl, PA

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Reference

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Off the Grid: Ultra-low Pressure Drip Irrigation and Rainwater Catchment

for Small Plots and High Tunnels

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Under Pressure

All forms of irrigation need a push or pressure to move water from its source to its destination. Water sources include wells, springs, lakes, creeks, canals, rivers, cisterns, elevated tanks, or municipal water supplies. The amount of pressure or push required depends on many things including the height water must be lifted, length and size of the delivery pipe(s), crop and size of the area to be irrigated, and the distance water needs to be moved from the source to the field, greenhouse, or tunnel.

Pressure to move water and operate an irrigation system is created in several ways including all sorts of pumps. Pumps include diesel- or gasoline-fueled motorized pumps or electric pumps powered by an electricity grid, batteries, or directly from solar photovoltaic (PV) panels. Pumps vary greatly in size, power, pressure and capacity, so growers need to first estimate their crop size and water requirements and work backwards to determine power requirements, pump size and type.

Pressure can also be obtained by the weight of water itself and gravity-fed water delivery systems have been used in some parts of the world for centuries. Water creates pressure of 1 pound per square inch (1 psi or 0.068 atm) for every 2.3 feet (0.7 m) it is raised above the surface of the area to be watered or irrigated:

2.3 ft. elevated water = 1 psi

If, for example, we plan to irrigate from a pond that is on a hill so that the pond's water level is 25 feet above the field to be irrigated, water from the pond will have about 11 psi of pressure for irrigation (25 ft ÷ 2.3 ft/psi = 10.9 psi). And if a tank is filled to a level of 3 ft above the ground, that provides about 1.3 psi to irrigate a plot at ground level (3 ft ÷ 2.3 ft/psi = 1.3 psi). This is true regardless of tank size so that a 10-gallon tank with its water level at 3 ft will create the same pressure as a 500-gallon tank with its water level at 3 feet (**Figure 1**).

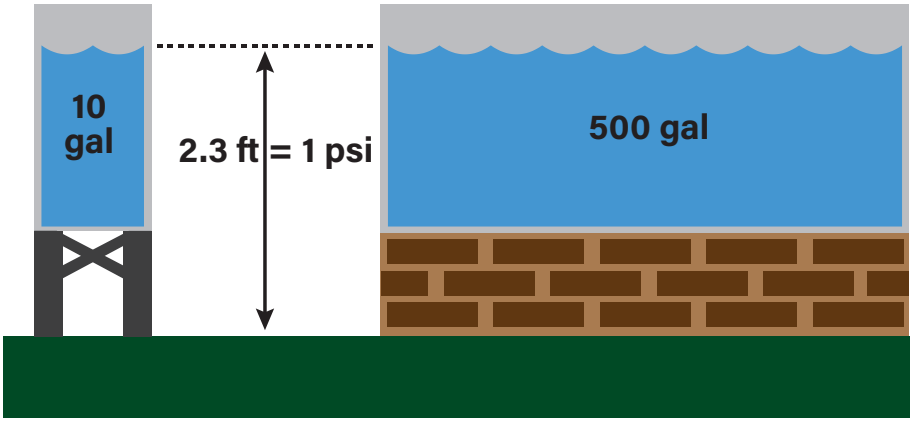

Figure 1. Large and small tanks at the same height will have the same pressure (about 1 psi in this example).

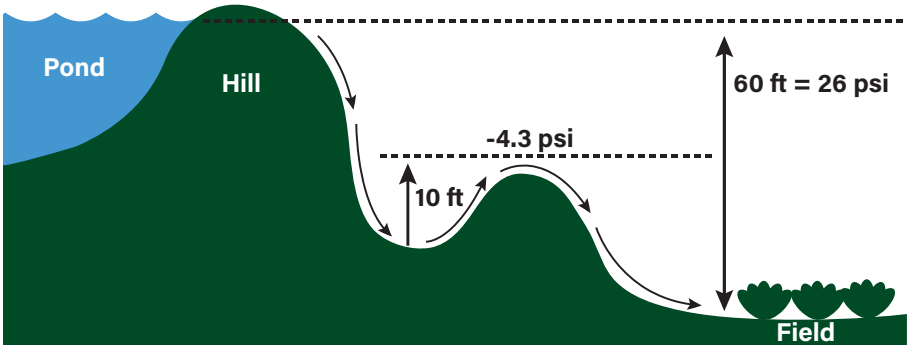

Figure 2. Gains and losses in pressure from a pond located above the field to be irrigated.

It is the elevation of the water column rather than capacity of the tank that determines pressure.

We use this simple principle when planning a pump-driven or gravity-fed irrigation system. Let's assume we are installing drip irrigation and our water source is a pond that is 60 feet higher than the field we want to irrigate (**Figure 2**). We can use pressure from the pond, which is equal to 26 psi (60 ft ÷ 2.3 ft/psi = 26 psi). But between the pond and field there is a small hill which rises 10 feet. This will reduce our 26 psi operating pressure by 4.3 psi (10 ft ÷2.3 ft/psi = 4.3 psi) so that our remaining available pressure at that point is 26 – 4.3 = 22 psi (**Figure 2**). That 4.3 psi of lost pressure from going up the small hill is regained, however, as the water descends again

from the small hill to the field. This does not take into account additional pressure losses from a filter or pipe fittings, friction in the delivery pipes, etc.

Conversely, water pressure can be expressed as the height of a water column. If we know that a pump or a city water supply generates 30 psi of pressure, that's equivalent to water in a tank that's almost 70 feet above ground level (30 psi x 2.3 ft/psi = 69 ft). Pump manufacturers usually provide this information in the form of feet or meters of pressure or "head" generated.

Low and Ultra-low Pressures for Drip Irrigation

Manufacturers of drip irrigation tubing publish operating pressures for their products and commonly recommend pressures in the 8-15 psi range. This is equivalent to a water tank that is 18 to 34 feet high (8 psi x 2.3 ft/psi = 18 ft; 15 psi x 2.3 ft/psi = 34.5 ft). These are considered low pressures compared with pressures required for other forms of irrigation like sprinklers. The main advantage of using low pressure forms of irrigation is that less energy is required from pumps and therefore less fuel is required. Smaller pumps can be used including solar-powered pumps. In addition, less expensive thin-walled delivery pipes and simpler fittings can be used.

While 8-15 psi is considered the normal range for drip, some companies have tested their drip lines at pressures as low as 3 psi which is equivalent to water levels about 7 feet high. Extension workers in Asia, however, recently discovered that, if the system is designed correctly, commercial drip irrigation tubing (i.e., drip "tape" or drip laterals) will function well for small plots up to ¼ acre (10,890 sq. ft or 1012 sq. m) at "ultra-low" pressures of only 1 to 2 psi. This is equivalent to water levels in tanks that are only 2 to 5 ft above ground level (**Figure 3**). This reduces initial pump costs, pump operating costs, and the difficulty of elevating and supporting heavy water tanks[1].

In a project to develop simple, low-cost drip irrigation systems for small farmers in Southeast Asia, hundreds of field tests demonstrated that water could be applied uniformly on small plots up to a quarter-acre using elevated tanks and pressures of only 1 to 2 psi. Carefully controlled tests at the University of Kentucky in 2014 and in Colorado by Robert Yoder (Affordable Village Solar) and Ryan Weber (iDE[2]) confirmed that the uniformity of water application through commercial drip tubing[3] is not significantly reduced on small plots at pressures of 1 to 2 psi compared with a standard drip pressures of 8 to 12 psi. The application uniformity tests in Kentucky were carried out on an area equivalent to the size of a commercial high tunnel (70 ft x 18 ft) with a total of 210 drip emitters (three 70-ft laterals, **Figure 4**).

This has significant implications for designing gravity-fed and low energy drip systems here in the United States and in developing countries. The only caution with such low pressures is that the uniformity of watering can be reduced considerably by small changes in elevation within the field to be irrigated, so ultra-low pressure drip systems are most suited to level fields and high tunnels.

In a Ball Aerospace and University of Kentucky-assisted project in Gujarat,

Figure 3. A low tank used to irrigate a small high tunnel with rainwater.

Figure 4. Test setup for measuring uniformity of watering from drip irrigation with only 1 psi system pressure.

[1]One gallon of water weighs 8.34 lbs. (3.78 kg), so a 300-gallon (1136 liter) tank full of water will weigh well over a ton.

[2]International Development Enterprises, Denver, CO. https://www.ideglobal.org/

[3]Toro Aqua Traxx™ (Toro Irrigation, Bloomington, MN: www.toro.com) drip tape with 12-inch emitter spacing was tested at Univ. of Kentucky and Azud drip tape (Murcia, Spain: www.azud.com) was tested in Colorado.

India[4], low-powered DC solar pumps of about 1 hp were successfully combined with ultra-low pressure drip irrigation in 2014-15 (**Figure 5**). Ten pumps were installed on 10 different farms where each easily and uniformly irrigated an acre of commercial vegetables. In these systems the solar pumps raised water from open wells to tanks which were raised 5 ft (1.5 m or 2.2 psi) above the surface of the fields to be irrigated; crops were irrigated by gravity from the tanks.

The systems in India were designed in part based on thousands of ultra-low pressure drip systems installed on high value fruit, vegetable, and flower crops in Myanmar (Burma) from 2009 to 2014. Several similar but smaller systems have been installed in high tunnels in Kentucky and are described below.

[4]Project supported by Affordable Village Solar, Delhi, India: http://www.paulpolak.com/_slide/affordable-village-solar/

Figure 5. One-acre field in Gujarat, India, irrigated using a combination of a 1 hp solar-powered DC pump and ultra-low pressure drip from a gravity tank (background); system pressure was 2-3.5 psi.

Figure 6. Three "tote" tanks joined together to collect rainwater from a small outbuilding in Wilmore, Ky. The tanks have a total capacity of 825 gallons and are used to irrigate an adjacent vegetable garden and high tunnel.

Water for Free—Rainwater Collection

As climate change and irregular rainfall patterns affect more U.S. states and countries around the globe, rainwater collection and storage are becoming increasingly important. Surprising quantities of rainwater can be collected from a high tunnel, greenhouse, home, barn, or outbuilding. An inch of rainfall on a rooftop of only 500 square feet (about 20 ft x 25 ft, or 46 sq. m), for example, produces about 300 gallons of water, or:

1 inch rainfall from 1000 sq. ft rooftop = 600 gallons

A high tunnel that is 90 ft long and 30 ft wide (2,700 sq. ft) has the potential to capture 1620 gallons of water from each 1-inch rain. If a catchment system on the tunnel captures 90 percent of the first half-inch of rainfall, that results in about 730 gallons of water. It's obvious from these numbers that the limitation is usually not the amount of water from rainfall but the available water storage capacity in the form of tanks, cisterns, retention ponds, etc. (**Figure 6**). Collected rainwater should be considered a supplemental rather than the primary source of irrigation water.

Untreated rainwater collected from rooftops, high tunnels, or greenhouses should only be used with drip irrigation. It should not be used for washing produce, hand washing, drinking, or come into direct contact with edible portions of vegetables (i.e., sprinkling onto leafy greens, etc.).

Collecting Rainwater from High Tunnels

It is relatively simple to attach gutters to the sides of high tunnels to collect rainwater. While professionally-installed seamless guttering is recommended, it is also possible to install gutters yourself using simple tools and sectional gutters available at home improvement stores (**Figure 7**).

Regardless of who does the installation, you may need to attach a supplemental wooden board below the tunnel's "hip board" in order to support the gutter (**Figure 8**). The hip board alone may not provide enough attachment surface to allow adequate sloping of the gutter from one end to the other. Gutters should be sloped 6 to 8 inches per 100 feet of length. This slope can be marked on the board with a chalk line before installing the gutter and can be checked before final installation by pouring water in the gutter at the high end. Make sure that the outlet or low end of the gutter is at least a few inches above the top of the water collection tank.

The supplemental board can be as simple as a 2 x 6 or 2 x 4 installed with pipe straps and self-tapping screws that secure straps to the tunnel bows (**Figure 9a and b**). The supplemental support boards may need to be cut at a diagonal for mounting on Quonset style tunnels (see the Iowa State University publication and video listed under **References**).

Professional gutter mounting brackets like the ones shown in **Figure 10** are far superior to those sold with do-it-yourself gutter systems (**Figure 11**)--we learned this the hard way. Professional sealants like the one shown in **Figure 12** are also recommended and available from home and roofing supply companies.

In the simplest systems, the ends of gutters are fitted with endcaps, downspout outlets, and short flexible downspouts leading to the opening in the top of the tank (**Figure 7**). A small section of gutter leaf guard or other screen can be cut out and placed over the downspout opening in the gutter to act as a simple removeable filter (**Figure 13**). If the end of the gutter is more than an inch or so above the tank it may also require a simple supporting structure like the one shown in **Figure 14**. This is a "quick and dirty" system and other more elegant arrangements can be made for handling overflow such as the floating ball valve used in a system developed at Iowa State University (see **References**).

Water Tanks and Fittings

Second-hand 275-gallon plastic "tote" tanks like those in **Figures 3** and **6** are available for $40-$100 and make good water storage tanks for small plots and tunnels. Some irrigation and tank dealers also sell outlet fittings designed for these tanks (**Figure 15**). You can also make your own outlet adapter using Ferrnco™ or similar flexible adapters (**Figure 16**). It is essential not to significantly reduce the tank's outlet diameter, which should be at least 1½ in. (inside diameter) if you are going to use low tank heights for ultra-low pressure drip.

Figure 7. While seamless gutters are preferred, sectional gutters sold in home improvement stores can also be used.

Figure 8. Hip board and gutter support board.

Figure 9a. Inside view of hip board and gutter support board.

Figure 9b. Bracket and self-tapping screw attach gutter support board to tunnel bows.

Figure 10. Professional grade gutter brackets.

While tote tanks usually have sufficiently large outlets, rain barrels and other tanks may come with a ¾-inch outlet that is usually too small for ultra-low pressure drip. In this case use a portable electric drill and hole saw to cut a larger opening for a bulkhead fitting. Bulkhead fittings (**Figure 17**), available in different sizes from irrigation dealers and tank suppliers, can also be used to make outlets in plastic tanks and barrels. When these are not available, inexpensive plastic fittings designed for electrical work (gray in color) can be used to make outlet fittings (**Figure 18**). These should be fitted with flat rubber washers or o-rings. Standard white PVC pipe fittings similar to the electrical fittings shown in **Figure 18** cannot be used because their tapered threads do not permit snug fits against tank walls.

Figure 11. Gutter brackets (not recommended) for use with do-it-yourself sectional gutters.

Figure 12. Professional grade gutter sealant.

Figure 13. Small section of "gutter guard" used to filter debris at the gutter outlet.

Figure 14. Simple gutter support structure made from treated pine.

Water left standing in tanks for a week or more could harbor mosquitoes and should be treated with *Bacillus thuringiensis* (Bt) tablets or "dunks."

Components for Ultra-low Pressure Drip

While water pressure at the tank outlet may be sufficient for using gravity-fed low-pressure drip in high tunnels and small plots up to about ¼ acre (**Figure 19**), that pressure is easily lost by using delivery pipe and fittings that are too small. Pressure is also lost though filters commonly used for drip irrigation.

Besides using a large diameter tank outlet, it is important that large diameter delivery pipes are used from the outlet to the drip lines. One and a half-inch or larger layflat or polyethylene flexible pipe works well and drip line "take-off" connectors can be attached directly to these pipes (**Figure 20**). The large inside diameter of these pipes eliminates most pressure losses due to friction. Any bends, kinks, or sharp turns in the pipe also cause pressure losses, so these should be as few and as smooth as possible.

A main shut-off valve, usually a simple ball valve, is required at the tank outlet (**Figure 21**); some second-hand tote tanks come already fitted with a valve (**Figure 16**). This valve and any valves for irrigation zones should be about the same inside diameter as the delivery pipes.

Although screen or disc filters (**Figure 22**) are routinely used for drip irrigation at higher pressures, they cause significant pressure losses, and it's not possible to use a standard filter with ultra-low pressures of 1 psi or less (3.2 ft tank height). Large diameter screen filters worked well with

Almost all research and testing to date of ultra-low pressure drip has been with lateral lengths of 100 feet (30 m) or less and longer laterals are not recommended without additional uniformity testing. Use of ultra-low pressures and solar pumping is just beginning and improvements are possible; the authors welcome your feedback and suggestions.

Figure 15. 1½-inch outlet fitting designed for a 275-gallon tote tank.

Figures 16a and 16b. Tote tanks with ball valves fitted to PVC pipe with Fernco™ couplings.

ultra-low pressure drip in India with tank outlet heights as low as 3½ ft. Greater losses may occur with disc filters which have not yet been tested at these low pressures; it may not be possible to use ultra-low pressure drip with unfiltered surface water. Filter size should not be much smaller than the delivery pipe diameter.

Fortunately, it is possible to filter out most large particles using a simple screen in the gutter outlet (**Figure 13**) or tank inlet when collecting rainwater from high tunnels. Some settling of finer particles also occurs in the tank itself and tanks will need to be cleaned periodically.

We have used unfiltered rainwater with drip for two seasons in a high tunnel at the UK Horticulture Research Farm without significant clogging. Algae will grow in the tanks, however, if water is allowed to stand for more than a few days, and algae can result in clogging of drip lines. Long-handled brushes and mixture of a soapy water and a little bleach solution (about 1 part bleach to 8-10 parts water) can be used to clean the inside of the tanks (**Figure 23**).

Sun Power

While the system described below is still in its testing stages and can certainly be improved upon by new users, we have successfully used small, inexpensive solar-powered direct current (DC) pumps with drip in a few high tunnels in Kentucky. Even though gravity can pro-

Figure 17. 2-inch bulkhead fitting for water tanks.

Figure 18a, b, c. Gray, 2-inch electrical conduit fittings (a) used to create a tank outlet which can be joined to standard white PVC pipe. A 2 3/8-inch hole saw was used to cut the hole in the tank (b). Different fittings are installed outside (b) and inside the tank (c).

vide sufficient pressure for drip when tanks are raised just a couple feet off the ground, there are cases when pumps must be used when tanks are on the ground and cannot be elevated. Sidewalls of high tunnels may be too low to use for rainwater catchment with an elevated tank (**Figure 24**). That said, however, one Kentucky grower discovered that gravity alone was sufficient to irrigate cut flowers uniformly with 10 drip lines in a 50-ft long tunnel when her ground tanks were at least half-full (**Figure 24**).

We installed an inexpensive (less than $200) solar pumping system to use together with ground tanks when water levels were too low to use gravity alone. This system consisted of a small 2-amp, 12 volt submersible bilge pump (for boats, **Figure 25**) coupled with a 9 amp-hour 12 volt battery, a 30 watt solar panel, and a small solar charge controller (**Figure 26**). Current (2017) costs for these components are shown in **Table 1**.

The solar panel simply keeps the battery charged while the battery powers the pump.[5] The controller is required to keep the panel from overcharging the battery in bright sunlight when power from the panel can exceed 19 volts.

We added an on-off switch, a 3-amp fuse, and placed the battery inside a cheap plastic "ammo box" which was mounted on a 4 x 4 treated post used for the solar panel

[5]While it is possible to use these pumps wired directly to the solar panel without a battery, this was not recommended by the manufacturer and may result in a much shorter service life of the pump.

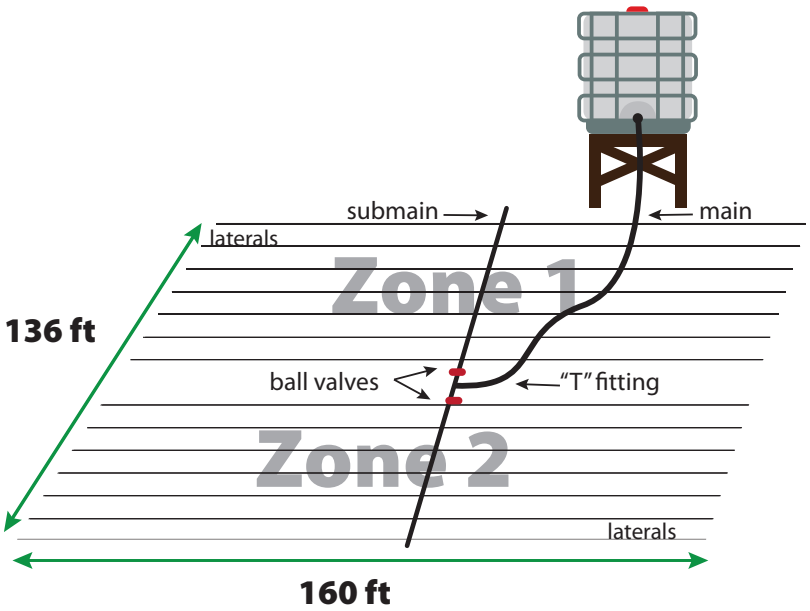

Figure 19. Larger plots up to an acre can be irrigated by dividing fields into ¼ acre zones using valves. A minimum height of 3 ft from the ground to the tank outlet and 2-inch diameter delivery pipe, valves, etc, are recommended for these larger plots.

Figure 20. Take-off connectors (with valves) for joining drip lines to a main or submain pipe.

Table 1. Costs for small solar pump & battery system for high tunnels

Rule™ 25S, 500 gallon per hour, 12-volt DC submersible bilge pump with automatic sensing	$65.00
12-volt 9 amp-hr sealed battery	$20.00
30 watt, 12-volt solar panel	$33.00
Morningstar Sunguard™ 4.5 amp 12V charge controller	$30.00
16-gauge landscape wire (10 ft @ $0.36/ft)	$3.60
waterproof wire nuts (6)	$2.50
3-amp fuse and fuse holder	$4.00
toggle switch	$8.55
plastic battery box ("ammo" box)	$5.00
4 x 4 x 8 ft treated post	$9.00
1/8 x 3/4 x 4 ft aluminum strip	$6.00
Total	**$186.65**

Figure 21. A main shut-off valve is required at the tank outlet.

Figure 22. Two-inch disc filter used for drip irrigation.

Figure 23. Cleaning a tote tank with detergent, chlorox, and a ceiling fan brush.

Figure 24. Tote tanks for rainwater collection from a high tunnel; the two tanks are joined by an underground PVC pipe. Drip lines in the tunnel are pressurized by gravity or the solar pump.

Figures 25a and 25b. Small 12-volt, 2 amp DC bilge pump used with a 12 volt battery and solar panel. The pump is attached to a scrap of Hardie™ board cut to fit inside the tank opening. Flexible marine bilge pump tubing is used as the pump's delivery pipe.

(**figures 24 and 27**). Several small holes were drilled into the bottom of the box to prevent rainwater accumulation, although this never became a problem. The fuse was wired between the battery and pump; we used 16-gauge outdoor lighting wire from the battery to the pump. Any exposed electrical connections were sealed with Liquid Tape™ and/or waterproof wire nuts.

The pump was attached to a piece of waterproof Hardie™ board which was cut small enough to fit through the opening on top of the tank (**Figure 25**). This board was attached to a 4-ft length of thin ¾-inch-wide flat aluminum stock available at home improvement stores. The aluminum strip could easily be fixed to the tank using a single bolt though a small hole drilled in the strip and lip of the tank opening (**Figure 28**).

Wires supplied with the pump had to be spliced and extended to reach the battery wires; these splices were soldered and then sealed (waterproofed) with shrink tubing and Liquid Tape™ (**Figure 29**). Although we first used the bilge pump in conjunction with a separate float switch from the same manufacturer, we later changed to a similar pump but with a built-in automatic switch for the system shown in **Figure 30**. This pump was easier to install and the point at which it switched on and off could be changed by moving it up or down within the tank using different mounting holes in the aluminum strip (**Figure 28**).

The solar-powered pump system in **Figure 30** was used to transfer water from the lower tank (foreground) to the higher tank at which point gravity was used to irrigate the tunnel.[6] The same type of solar pumping system was also used to irrigate a high tunnel directly from the tank at a site where tanks were on the ground (**Figure 24**). These tiny pumps supplied about 260 gallons per hour at pressures of 3 psi (2 m or 20 kPa) or enough for eight drip laterals in 90 x 30-ft tunnels.

[6]The pump could also have been used to irrigate the tunnel directly without gravity.

In Conclusion

Inexpensive ultra-low pressure gravity-fed drip systems have been developed which were adopted and successfully used by thousands of small farmers in Southeast Asia. These same simple design principles can be used in gravity-fed, solar, or a combination of gravity and solar-powered drip irrigation systems in small plots and high tunnels worldwide. It is also possible to combine such systems with rainwater catchment using tanks with outlets as low as 2 ft (0.6 m) above ground level (**Figures 30 and 31**).

Acknowledgement

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Figure 26. Small solar panel voltage controller.

Figure 27, Plastic "ammo" box used to house battery, solar controller, fuse, switch, and electrical connections.

Figure 28. Aluminum strip is bolted to lip of tote tank opening. Height of the pump in the tank can be adjusted using additional bolt holes in the strip.

References

Rainwater Catchment from a High Tunnel for Irrigation Use by Shawn Shouse and Linda Naeve. 2012. Iowa State University Extension and Outreach publication PM 3017. Available for download at: https://store.extension.iastate.edu/Product/13734 and as a video: https://www.youtube.com/watch?v=XsxRZQR_7VU

Design, Introduction, and Extension of Low-pressure Drip Irrigation in Myanmar by Brent Rowell and Mar Lar Soe. 2015. HortTechnology 25: 422-436 (August 2015). Summary: http://horttech.ashspublications.org/content/25/4/422.abstract. Pdf is available from the author.

For an in-depth review of drip irrigation experiences in developing countries see also *Drip Irrigation for Agriculture, Untold Stories of Efficiency, Innovation, and Development*. 2017. Jean-Phillipe Vernot *et al.* (editors). Routledge. New York. 384 p.

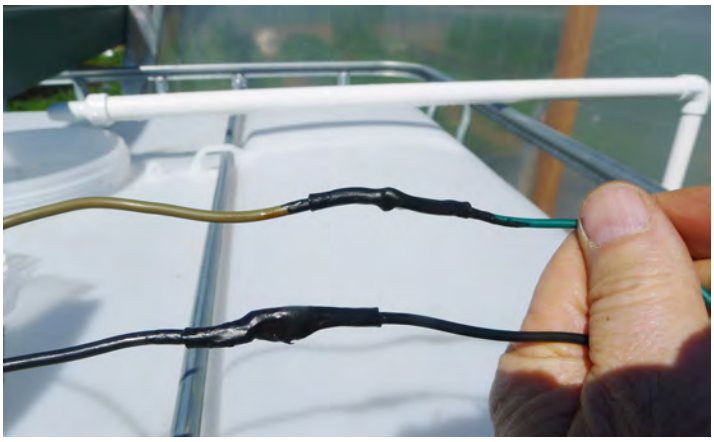

Figure 29. Waterproofed electrical connections soldered and sealed with shrink tubing and Liquid Tape™.

Figure 30. Rainwater collection and ultra-low pressure drip system on a tunnel at the UK Horticulture Research Farm. Solar pump is used to transfer water from the low tank (foreground) to the higher one.

Figure 31. Simple design principles can be used in gravity-fed, solar, or a combination of gravity and solar-powered drip irrigation systems.

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Rainwater Catchment from a High Tunnel for Irrigation Use

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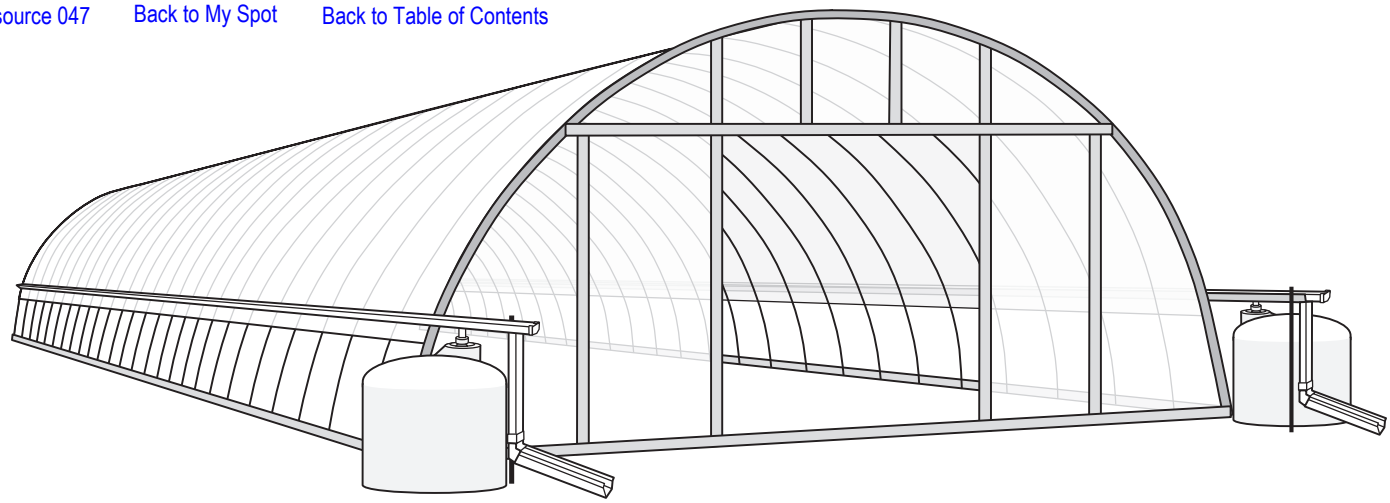

High tunnels, also referred to as “hoop houses,” are simple, plastic-covered, passive solar-heated structures in which crops are grown in the ground. High tunnels resemble greenhouses, but are less expensive to construct and maintain. Fruit and vegetable growers use them to extend the growing season and intensify production in cold climates. The advantages of growing crops in high tunnels rather than in fields are:

- Extended seasons
- Weather protection
- Labor efficiency
- Environmental control
- Reduced incidence of plant diseases
- Improved quality
- Increased revenue per square foot

High tunnel production is considerably different from field production. More detailed attention is required on water and nutrient management, temperature control, crop selection, and continuous production strategies. The covered area in a high tunnel creates a desert-like environment so irrigation is required. Also, since every square foot offers profit potential, high tunnel production requires additional attention to appropriate drainage around the structure. The expanse of a high tunnel yields a large volume of water with every measurable rainfall. Approximately 900 gallons of water will flow from the roof of a 30' by 96' high tunnel with a half-inch rain event. Unless the high tunnel site is elevated from the surrounding area and/or has drainage tiles installed around the perimeter, water accumulates and creates puddles around the sides of the high tunnel. This can create erosion problems as well as saturated soil on the inside edge of the high tunnel.

Described in this publication is a system to catch, store, and reuse the rainwater for irrigation in the high tunnel. The amount of water collected from periodic rain events often can be enough to irrigate and sustain a high tunnel for a few days to weeks. However, the water supply is not consistent and should not be the only water source for high tunnel crops. The ideal time to install a gutter system is at the time of construction because excess plastic from the cover can be utilized and support boards can be installed efficiently. However, gutters can be retrofitted on existing high tunnels.

The cost of installing rain gutters, rainwater storage tanks, and an electric pump to a high tunnel is estimated at approximately $1,200 (2011). A solar-powered pumping system will add approximately $700 to that cost. These estimates do not include

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the drip irrigation equipment and lines or the installation labor (approximately 70 hours). Investment in a rainwater catchment system may result in reduced expenses for drainage improvement and site modification and does not require long-term changes in the soil and terrain.

Rainwater catchment and reuse does result in savings on water supply costs. Iowa average monthly rainfall ranges from approximately 2.5 to 5.0 inches per month from April through October. With storage capacity to capture the first half inch of each rainfall event and some losses at the roof edge, an average of 1.5 to 2 inches of rainfall may be captured each month; however, the range may be from less than half an inch to more than 3 inches. Total growing season rainwater capture with storage for the first half inch should be approximately 40-50 percent of the growing season rainfall, or about 10 to 12 inches on the roof area of the high tunnel in Iowa (two 500-gallon tanks collect approximately 20,000 gallons per season from a 30' by 96' high tunnel). Increasing the storage tank size to collect the first inch of rainfall should capture 60 to 70 percent of the growing season rainfall, or about 14 to 17 inches on the roof area of the high tunnel in Iowa (two 1,000-gallon tanks collect approximately 28,000 gallons per season from a 30' by 96' high tunnel).

NOTE: Water collected from runoff from the high tunnel should be used only for irrigation through a drip irrigation system. Due to potentially high bacteria levels, it should never be used for consumption or for overhead irrigation of food crops.

The system consists of two components – the catchment and storage and the drip irrigation system.

Catchment/gutter components for two sides

Item	Quantity
115V industrial diaphragm pump	1
10' long vinyl gutter section	Enough for the length of both sides plus an extra section per side
Vinyl gutter brackets	3 per 10' gutter section
Gutter slip joints	1 per gutter section
Gutter mounting screws	4 per 10' gutter section
Gutter seal lubricant	1 bottle/tube
1.5" pipe straps (conduit clamps) and 1.25" construction screws or bolts and nuts to attach support board to high tunnel frame	1 set per ground post
Vinyl high flow drop outlets	4
Vinyl downspouts 10'	2
Downspout elbow	2
Downspout adapters	2
Vinyl gutter end caps	2
Lumber for gutter support (12' long 2 x 4's)	Enough for the length of one side plus an extra 12 feet
Weatherproof water storage tanks (at least 500 gallon capacity each for 30' by 96' high tunnel)	2
Tank outlet valves	2
Hose adaptors to fit valves	2
Large, inflatable children's vinyl balls (approx. 13" diameter or whatever will fit through the tank top opening)	2
Small machine nuts to thread onto #9 wire (#4-40)	16
Coated #9 wire	25 feet
Garden hoses	2, each long enough to extend from a tank to the pump
Solar-powered pumping system	
12V industrial diaphragm pump	1
12V photovoltaic solar panel with mount	1
12V deep cycle storage battery	1
Solar charge controller	1
Wiring to connect panel, battery, controller	

Irrigation components

Item	Quantity
200 mesh filter	1
Power switch	1
Pump (see page 5)	1
Power source (electricity or battery)	
8 to 12 PSI pressure regulator	1
Header line ("layflat" hose or ¾" polyethylene tube)	Width of high tunnel
¼" connector tubing	Approximately 2' per drip line
Drip lines	Length varies with number of rows
Drip line emitter valves	2 per line
Adaptors and fittings for: Hose to filter Filter Pump Header line	
Hose clamps	4 to 6
Drip line ends	For each line

Vinyl gutters are recommended because they are assembled with slip joints and clip brackets that allow for easier installation and seasonal removal from the high tunnel. They are also less likely to tear the plastic than metal gutters.

Water Collection Tanks

Before installing the gutters, select the appropriate-size water tanks for your system. The needed capacity depends on the size of the high tunnel and the amount of water desired to irrigate the crop in the tunnel. Each 1,000 square feet of high tunnel roof will yield approximately 300 gallons of water from a half-inch rain. Gutters and tanks on each side of the tunnel will capture the maximum amount of water possible and water can be drawn alternately for irrigation needs. It is best to have a tank capacity that will nearly empty with each irrigation event. Draining the tanks frequently will prevent excess buildup of algae. Purchase new tanks or used tanks that have held only clean water. Short, wide, plastic tanks with a fairly large opening on the top and a drain near the bottom are ideal. The top of the tank opening should be at least 8 to 12 inches lower than the height of the low end of the gutters. Place the tanks at the corners of the high tunnel at one end. Level the area for the tank location. Align the tank fill opening so the gutter will drop the water in the center of the opening. In the bottom opening of the tank, install necessary fittings to attach a garden hose and shut-off valve. Water tanks can be lightweight when empty. Secure the tanks to the ground with earth anchors and rope or straps.

Gutter Installation

The gutter brackets are attached to the high tunnel on a support board that slopes downward to the tank end of the high tunnel. The ribbon board (hip board) on the high tunnel may not be wide enough to accommodate the slope required for the gutters to drain. A 6- to 8-inch drop per 100 linear feet is recommended for the water to flow adequately toward the tank. A dedicated support board, such as a 2 x 4, may need to be installed below the ribbon board. This support board can go near the top of the plastic roll down sides, on the inside of the plastic, or at the top of a drop down ventilation system. Due to the curved sides on a Quonset style high tunnel, split the 2 x 4 diagonally and attach the cut side to the tunnel (See Diagram 1.). This will provide a more vertical surface for attachment of the gutter brackets.

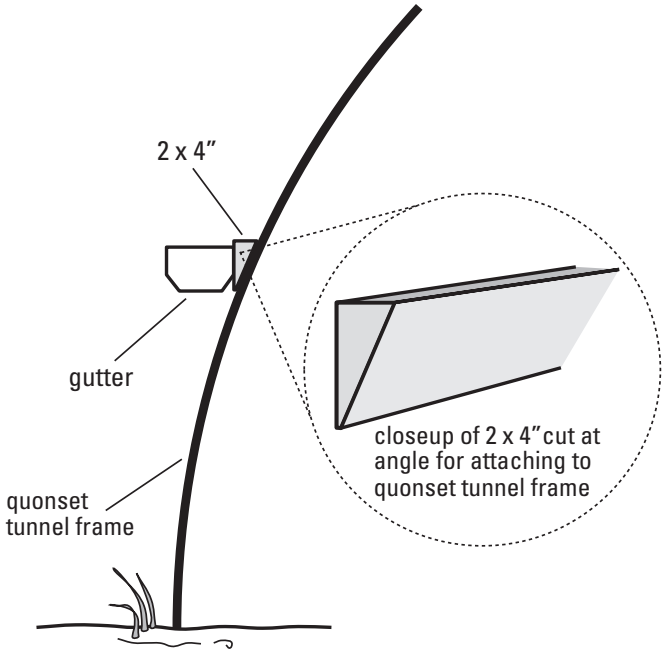

Diagram 1. Gutter support board mounted on a Quonset high tunnel.

This diagonal split of the support board is not necessary for gothic style buildings that allow the support boards to be installed just below the ribbon board. If you use full-size (not split) 2 x 4 lumber for a gothic tunnel, the lumber requirements in the table on page 2 will be doubled. Stretch a carpenter's string from one end of the high tunnel as a guide for attaching the support board, allowing for the required drop in elevation. The support board should extend beyond the end of the high tunnel and across the width of the tank. Attach the end of the extended support board to a steel stake or wooden post driven in the ground.

NOTE: Before installing the support board, be sure the height on the lowest end of the support board is at least 8 inches higher than the opening on the collection tank. It may be necessary to dig the tank into the ground slightly if it is too tall.

Starting at the high end of the gutter, measure 10-foot intervals along the support board where the center of the slip joints will be installed to splice the 10-foot gutter sections together. Allow for the gutter joint gap specified by the gutter manufacturer. Align the slip joints on a uniform downward slope toward the tank using a string line or sight method to assure uniform slope. Install three gutter brackets, evenly spaced, between the slip joints.

When you reach the tank end of the tunnel, install a drop outlet centered over the tank opening. Install a second drop outlet just beyond the edge of the tank. Install gutter brackets if needed between the drop outlets. Install the gutter sections into the brackets and slip joints using the joint lubricant. Cut sections of gutter to fit the lengths between the last slip joint on the high tunnel and the drop outlet over the tank, and between the two drop outlets. Attach a downspout elbow and downspout to the final drop outlet to direct excess water away from the tank and tunnel (See Diagram 2.).

Because high tunnel buildings typically do not have an overhanging eave or drip edge, provision must be made to get the water off the roof and into the gutter. One simple method is to attach a flap of additional plastic to the tunnel roof, which can hang into the gutter. This flap of plastic may be attached to the roof

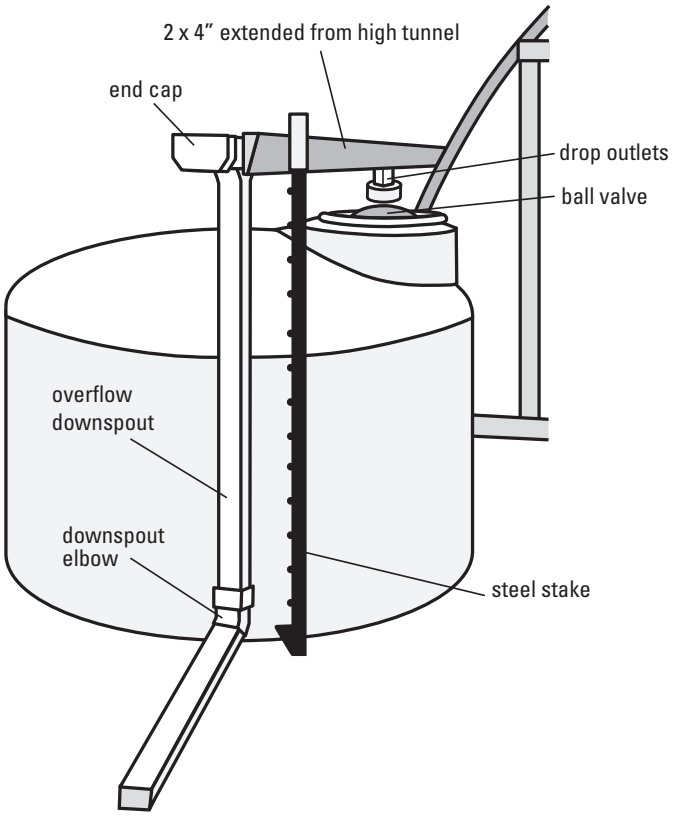

Diagram 2. Water Catchment System.

by locking the top edge of the flap under the channel wire on the ribbon board. The flap length will increase as the gutter slopes farther below the channel board. The bottom edge of the flap should nearly touch the inside bottom of the gutter. Another method is to use a uniform width flap that is taped to the tunnel ventilation curtain a few inches above the gutter top edge using tunnel repair tape. Attaching a taped flap around ventilation curtain stay ropes may prove challenging. Taped narrow flaps may resist dislocation by wind better than wider flaps, but taped joints may require more frequent maintenance. Wider flaps attached under channel wires may require less maintenance, but may require weights at the bottom edge or other means of holding the bottom edge inside the gutter during windy conditions. Remember that in freezing climates, winter removal of the gutters may be necessary to prevent ice and snow damage to the gutters and supports.

The plastic film covering on gothic high tunnels end at the ribbon board; the sides are separate pieces of film. After attaching the film covering,

the excess plastic from the roof can be used to direct the water into the gutters. If the plastic has been trimmed close to the channel on existing high tunnels, an additional strip of plastic the length of the tunnel and wide enough to nearly reach the bottom of the inside of the gutter can be attached using channel wire.

Tank Overflow Valve

An overflow valve diverts excess water away from the tank and into a waterway or other containment or holding apparatus. Simple float valves using large, vinyl, inflatable child's balls are easy to install and effective for this purpose. For each tank, select a large ball that will fit in the opening of the tank. A basket can be made out of #9 wires bent into U shapes. Make the basket deep enough to accommodate the ball and about 4 to 6 inches above the ball for the water to flow from the drop outlet above the tank. Thread the end of the wires so the basket can be attached to the upper lip of the tank with small machine nuts. Attach a downspout adapter to the end of the drop outlet over the tank opening using small screws and seal the joints to prevent water from leaking after the valve closes (See Diagram 3.).

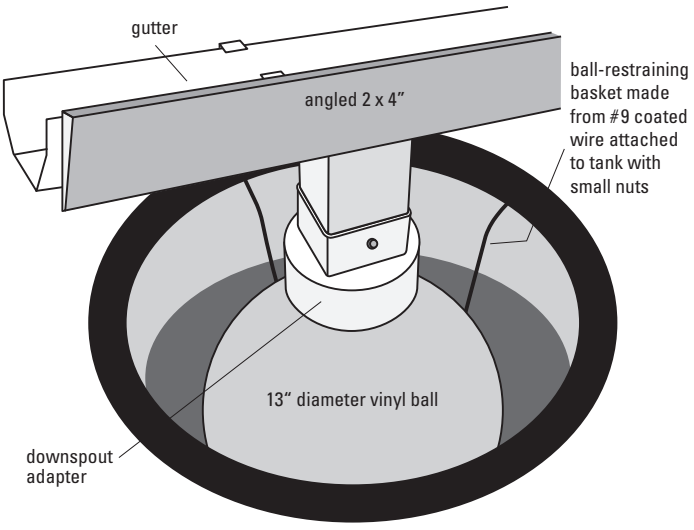

Diagram 3. Ball Valve in Tank.

How it works: As the water level nears the top of the tank, the floating ball in the basket will rise and eventually seal against the downspout adapter, preventing more water from entering the tank. Any additional water flows over the blocked drop outlet to the next drop outlet and downspout for transfer to another holding tank or surface drainage away from the high tunnel.

Pumping System

Recycling collected water through an irrigation system requires a pump to pressurize the water. For drip irrigation systems, small electric diaphragm pumps work well. Size the pump to match the irrigation flow rate (gallons per minute) required for the irrigation system. If the flow rate of the pump is higher than the irrigation system flow capacity, use a self-limiting pressure switch pump to avoid excessive pressure build-up or rapid on-off cycling of the pump. Precede the pump with a 200-mesh filter to remove debris that may accumulate in the storage tanks.

When electric power is not available, a solar-powered 12-volt or 24-volt DC pump may be used. Connect the pump to a deep-cycle battery of the proper voltage. Appropriate battery capacity (amp-hours) can be estimated by multiplying the pump current rating (amps) by the number of pumping hours between battery charging times, with a safety factor built in. For example, if the pump draws 3 amps and you expect to pump 7 hours per day, and you want to be able to pump 2 days without the need to recharge the battery—this would require 7 x 3 x 2 = 42 amp-hours of battery capacity. Allowing for only 50 percent discharge of the battery, you would look for a battery with at least 84 amp hours of capacity.

Consult with a solar panel provider to select a solar panel appropriate for recharging the battery. Or estimate the needed panel capacity by matching the solar panel (or group of panels) voltage to the battery voltage and dividing the battery capacity (volt-amps) by the number of hours you would like to allow for battery charging. For example, if the battery capacity is 84 amp-hours and you would like to allow two 10-hour days for charging, your solar panel or panel array would need to provide 84/20 = 4.2 amps of current for charging. These estimating methods are only rough approximations. Solar panel providers may have more precise estimating methods.

Solar panel charging performance can be enhanced with the addition of a solar charge controller. Charge controllers allow charging to occur in lower sunlight intensities and prevent battery power from bleeding back to the solar panels at night. Refer to recommendations from manufacturers and suppliers to select an appropriate charge controller.

Maintenance

Summer care – Maintain the gutter system by periodically checking for leaks or obstructions. Check the flaps of plastic film that divert the roof water into the gutters to make sure they are intact and properly positioned. Sunlight and warm water temperatures may encourage algae growth in the water storage tanks. Check and flush the filter at the pump each time you irrigate with the collected water. Using the stored water at the first opportunity and shading the top of the storage tanks may help limit algae growth. Check the overflow valve and excess water diversion system weekly to make sure all parts are operating properly. If you use a solar pump and charging system, monitor the charge status of your battery after pumping events and keep your solar panels clean and properly positioned. Monitor the performance of the pump by recording the time required for pumping a known number of gallons from the storage tanks. If the pump performance is lower than expected, check your filters, pressure regulators, and lines to make sure they are clean and free of kinks or obstructions.

Winterization – In freezing climates, it may be necessary to remove the gutter system in the winter to prevent damage to the gutters from ice and snow. Snow and ice may slide quickly off the plastic roof, damaging the gutters and mounting brackets. Vinyl gutter sections can be removed from the gutter mounting brackets and slip joint connectors and stored for the winter. Gutter mounting brackets themselves may be left on the high tunnel and are less likely to be damaged by snow and ice. Drain the storage tanks as much as possible prior to freezing temperatures and remove or drain the pump and all plumbing. For solar systems, store the battery in a shop or garage for the winter. Solar panels may be removed and stored for the winter or left in place if the electrical leads are shorted together to prevent the panels from overheating.

Drip Irrigation System

The covered high tunnel creates a desert-like environment that requires regular irrigation. Drip irrigation is an efficient and accurate way to water crops in a high tunnel. It uses a low flow rate and supplies water only to the root zone of the plants. Drip irrigation is often used with plastic mulch for transplanted crops to conserve moisture and create a more consistent moisture level in the soil.

The drip tape requires a low pressure, 8 to 12 psi, at the main line. The water pressure can be maintained with a low flow pressure regulator after the pump and before the header line. A pressure regulator reduces incoming water pressure to a set pressure usable by a drip system. It is used when the incoming pressure is too high for the emitters or fittings. The flow rate of the regulator should be matched with the system.

The header line, a layflat hose or a ¾-inch polyethylene tube, is connected to the pump with appropriate-sized fittings. The lateral lines or drip lines, such as T-tape®, run the length of the rows (under the plastic mulch) and are typically attached to the header line with ¼-inch tubing and valve fittings (See Diagram 4, page 7).

It is necessary to have a "back up" line from your primary water source for use during dry periods. This line can be attached to the drip system by bypassing the pump.

To learn more about the use of drip irrigation in a high tunnel, refer to the Iowa High Tunnel Fruit and Vegetable Production Manual listed under additional resources.

Additional Resources

Naeve, Linda, Henry Taber, Eldon Everhart, Donald Lewis, and Ray Hansen. 2010. *Iowa High Tunnel Fruit and Vegetable Production Manual*. Iowa State University. Available to download as a pdf at **https://store.extension.iastate.edu/ProductList.aspx?Keyword=high%20tunnel**

http://www.hightunnels.org

http://www.iowaproduce.org

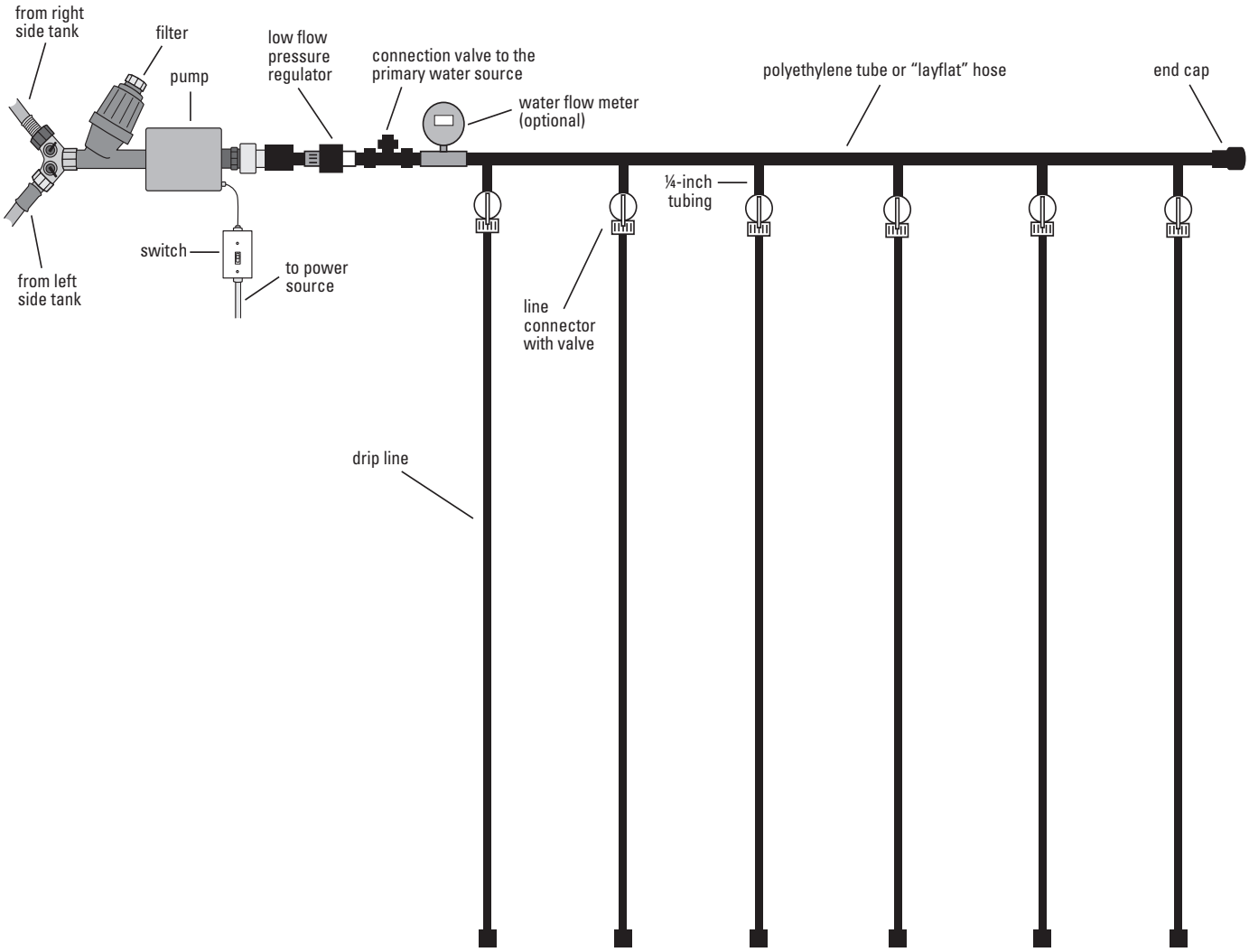

Diagram 4. An Example of a High Tunnel Drip Irrigation System using Harvested Rainwater.

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Rain Barrels Part IV: Testing and Applying Harvested Water to Irrigate a Vegetable Garden

Fact Sheet FS1218

Cooperative Extension

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Summer months are the time of year when having a rain barrel can really be useful. Heavy thunderstorms fill up rain barrels quickly, storing water for hot, dry days when there is no rain in sight. Rain barrel water is usually soft, meaning free of dissolved minerals and slightly acidic which is excellent for nutrient uptake by plants.

One of the most common questions asked about rain barrels is whether water harvested from a rooftop is safe to use on a vegetable/herb garden. Limited studies have been conducted focusing on the safety of roof runoff for vegetable garden irrigation. Gardeners often collect water in a rain barrel with little to no protection from the roof's "first flush" of runoff. The first flush water is the initial rainwater that drains off an impervious surface, such as a driveway, parking lot, or roof and has been shown to have the highest levels of contaminants. Larger rain water collection systems (cisterns) that collect hundreds or thousands of gallons of water are normally installed with a first flush diverter which reroutes the first few gallons of rainwater away from the storage container. Rain barrels are often not installed with this feature.

Research has shown that roof runoff can have high levels of pathogens, zinc (Zn), lead (Pb), and polycyclic aromatic hydrocarbons (PAHs) (Bannerman et al., 1993; Clark et al., 2008; DeBusk, 2009; Van Metre and Mahler, 2003; Gikas et al., 2012). These metals and compounds may be hazardous to human health if ingested in specific concentrations. The question is whether these levels are high enough to be of concern for a backyard or community gardener who uses a rain barrel to water a garden grown for consumption.

This fact sheet summarizes the findings of one New Jersey study investigating the water quality of rain barrel water (Haberland, Bakacs & Yergeau, 2013). In addition, recommendations are made for testing rain barrel water and how to safely utilize rain barrel water to irrigate a home, community, or school garden.

Water Quality Study

Twelve rain barrels were installed during the summer of 2011 on homes that have asphalt shingled roofs, the dominant roof surface on New Jersey houses. Six barrels were located in a suburban community and six in an urban community to help determine the effect of surrounding land use on rain barrel water quality. Samples were collected six times from each barrel over a four month period from July-October. Water samples were collected 3–7 days after a rain event in order to mimic the amount of time a homeowner or community gardener would wait before using the collected runoff. Samples were analyzed for PAHs, Pb, Zn, and total coliform and *Escherichia coli* (*E. coli*) bacteria. *E. coli* is a species of bacteria that is specific to fecal matter from warm-blooded animals such as squirrels and birds. The presence of *E. coli* indicates the potential presence of human pathogens, i.e. bacteria, and is important

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information if rain barrel water is used to water a vegetable garden.

Having a standard against which to compare the level of contaminants in the roof runoff is important for determining the safety of the water for irrigation. Table 1 shows the water quality standards against which the data were compared. Both Pb and Zn were compared to the United States Environmental Protection Agency (USEPA) reclaimed water (treated waste water) guidelines (USEPA, 2012) for agriculture irrigation because no other irrigation standards exist for these parameters. No irrigation standards exist for total coliform. *E. coli* results were compared to the US Food and Drug Administration's (USFDA) proposed standards for "Growing, Harvesting, Packing and Holding of Produce for Human Consumption" (USFDA, 2011).

Results were also compared to the New Jersey Drinking Water Standards although in New Jersey harvested rainwater can not normally be used as a source of drinking water per the Safe Drinking Water Act (NJDEP, 2011).

Table 1: Water quality standards for comparing test results

Parameter	Federal Irrigation Standards	NJDEP Drinking Water Standards[1]
Lead	5.0 mg/L[2]	0.015 mg/L
Zinc	2.0 mg/L[2]	5.0 mg/L
Total coliform (counts/100 mL)	n/a	based on presence/ absence
E.coli (counts/100 mL)	geometric mean= 126/100 mL[3] single sample limit= 235/100 mL[3]	based on presence/ absence

[1]USEPA, 2012
[2]USFDA, 2011. The standard calls for maximum E. coli levels in agriculture irrigation water of <126 counts/100 ml for the geometric mean (must have 5 samples) and <235 counts/100ml for one sample.
[3]NJDEP, 2011. Coliform bacteria standards are based on the presence or absence of coliforms in a sample. When collecting less then 40/samples per month, no more than one coliform sample can be positive.
mg= milligrams, L= liters, mL= milliliters

Results

Results of this study showed that overall the water quality of the rain barrel water was very good. Heavy metals were well below federal irrigation standards for reclaimed water and posed minimal risk for irrigating a vegetable garden. PAHs were not detected in any samples. Results also showed the majority of water samples to be below recommended irrigation guidelines for *E. coli*. Table 2 shows the percent of samples that violated the federal irrigation standard and the New Jersey drinking water standards.

Table 2: Percent of samples above the standard

Contaminant (total # of samples)	Federal Irrigation Standards	NJ Drinking Water Standards[1]
Lead (72)	0%[2]	4%
Zinc (72)	0%[2]	0%
Total coliform (71)	n/a	Present in 100% of samples
E.coli (47)	9% (single sample limit only)[3]	Present in 66% of samples

[1]USEPA, 2012
[2]USFDA, 2011
[3]NJDEP, 2011

- Zn values did not violate any of the water quality standards although Zn levels were higher in samples taken from urban barrels than the suburban barrels. Atmospheric Zn can come from tire dust and industrial processes (Councell, 2004). Both increased traffic and industrial processes involving metals may be the reason Zn was higher in urban samples.
- Pb values did not violate the irrigation standards at any site. Three of the samples violated the drinking water standard for Pb. The main source of Pb is most likely from atmospheric deposition due to industrial processes, manufacturing industries, waste incineration, and airborne soil dust (USEPA, 2006a). Pb results showed no difference between urban and suburban land uses.
- Total coliform violated the drinking water quality standards at all sites for all samples. This is not necessarily a concern for irrigating vegetable gardens though because total coliform is found in rainwater and is a poor indicator of human pathogens.
- *E. coli* violated the irrigation standards in 9% of the samples collected. *E. coli* violated state drinking water standards in 66% of the samples collected.

In this study, potential sources of pathogens were wildlife (i.e. birds, squirrels) that had access to the roofs that were monitored or living in trees adjacent to the homes.

Best Practices and Recommendations

Even though a low percentage of samples exceeded the irrigation limits, caution is still warranted when using harvested water to water a vegetable/herb garden to reduce the risk of exposure to a harmful contaminant like *E. coli*. Below is a list of recommendations for pathogen treatment and best practices for utilizing collected rain water to irrigate vegetable/herb gardens.

- Rain barrel users should make sure to clean the barrel with a 3% bleach solution before collecting water to irrigate a vegetable/herb garden. Household, unscented bleach with a 5–6% chlorine solution can be added at the rate of 1/8 teaspoon (8 drops) of bleach per gallon of water. A typical 55 gallon rain barrel would need approximately one ounce of bleach added on a monthly basis. During periods of frequent rainfall, bimonthly treatment may be necessary. Wait approximately 24 hours after the addition of bleach to allow the chlorine to dissipate before using the water. Note that household bleach is not labeled for use in water treatment by the Food and Drug Administration although it is frequently recommended for emergency disinfection of drinking water (USEPA, 2006b).
- When using harvested water to irrigate a vegetable garden, care should be taken to avoid getting water on the plant itself. Harvested rainwater should only be applied to the soil, possibly through drip irrigation. A watering can may be used, as long as the water does not get directly on the plant.
- Water should be applied in the morning only. Produce harvesting should not take place right after watering in order to benefit from leaf drying and ultraviolet light disinfection.

Testing Harvested Rainwater

Guidelines on using harvested water often recommend having the water tested by a commercial lab to determine the safety of using the water on an edible garden. The results of this study show that testing harvested water at the necessary frequency needed to draw meaningful conclusions about the water quality is impractical and too expensive for the average homeowner, community, or school garden. Rather, it is recommended that the rain barrel user automatically treat the water, and take appropriate best practices, if it will be used to irrigate a vegetable/herb garden.

However, testing may be necessary to comply with state or federal guidelines. For example, school or community gardens may have to test water sources used for irrigation to show that the produce is safe for student consumption. The National Food Service Management Institute recommends testing non-municipal water sources for a school garden annually (NFSMI, 2011). The following steps should be followed for having the water tested.

- At a minimum, *E. coli* testing should be conducted. Local county health departments may perform this type of service for residents or may have a list of water quality laboratories that test for *E. coli*. The NJDEP lists water quality labs on their website by county at nj.gov/dep/oqa/certlabs.htm. In addition, it may be possible to have the water tested through a local well water testing program. It should be made clear to the laboratory that the water is utilized for irrigation purposes and not for drinking water.
- Most laboratories provide sampling bottles. The water sample should be taken from the rain barrel's faucet or hose and not dipped into the top of the barrel.
- Pathogen samples must be kept in a cooler in ice and returned to the laboratory within six hours of taking the sample.
- Results can be compared to the irrigation standards for *E. coli* listed in Table 1. For individual samples, if *E. coli* values are under 235 counts/100ml then the water would be safe to use for irrigation.

Conclusions

Based on study results, rain barrel water can be safely utilized to irrigate a vegetable/herb garden. Pathogen treatment should be conducted and best practices utilized when applying the water. Testing rain barrel water is not a practical method for the average homeowner or community/school garden for determining water quality but may be necessary based on state guidelines. Additional information on water quality considerations for harvested rain water can be found in Mangiafico and Obropta (2011).

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OKLAHOMA COOPERATIVE EXTENSION SERVICE BAE-1757

Design of Rainwater Harvesting Systems in Oklahoma

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Introduction

Rainwater harvesting is the process of capturing, channeling, and storing stormwater runoff for later use. Ideas and technologies of harvesting rain date back more than 4,000 years in areas such as Rome, the Middle East, and China. Ancient societies left evidence of agricultural dams and runoff control methods, as well as reservoir or cistern construction in urbanized areas. As of 2004, an estimated 100,000 residential rainwater harvesting systems were in use in the United States and its territories (TWDB 2005).

Rainwater harvesting systems can be easily implemented at the home, commercial, and community level. The two basic types of rainwater harvesting collection systems, cisterns and rain barrels, essentially differ because of the volume of water to be collected. These methods of collection and storage augment municipal and well-water supplies, reduce flooding and erosion, improve water quality, and reduce water bills.

Uses of harvested rainwater include irrigation, washing cars, flushing toilets, and drinking water. Atmospheric contaminants such as, vegetation overhang, infrequent rains, dust accumulation, roof material, and bird and rodent droppings, can be carried into the system by rainwater. Therefore, if used for drinking water or flushing toilets, the water must be treated in accordance with state and federal drinking water regulations. Treatment methods include, but are not limited to, debris filtration and various purification methods such as chlorination or UV treatment to achieve disinfection.

Design and Sizing

The five main components of a rainwater harvesting system are (1) conveyance, (2) storage, (3) overflow, (4) outlet, (5) delivery. In addition, a first-flush diverter can be installed for improved water quality. Before implementing a rainwater harvesting system, it is important to understand and consider the function of these components, as well as familiarizing oneself with local plumbing, building, neighborhood, and environmental codes. The limiting factors in most rainwater harvesting applications are the space available for storage, cost and aesthetics. Several factors must be considered when installing a system including contributing rooftop area, rainfall patterns, and anticipated usage.

Different approaches to rainwater harvesting are taken in different parts of the country. To begin a rainwater harvesting project, consider the following:

- How will the harvested rainfall be used?
- How reliable will you need the system to be?
- What is the size of the catchment area that you have or need?
- Where is the catchment area located relative to the intended use?
- What size and type of storage do you have/need to purchase for the harvested rainfall?

The catchment area should be calculated based on the footprint created by the roof and not by the square footage of the roof surface. Be sure to use roof surfaces as near as possible to the planned cistern location, to shorten pipe runs. Because precipitation and water demand (except for in-home demand) are very uneven during the year, the cistern size is based upon monthly average precipitation and demand. These can be obtained from Table 1 by multiplying your average annual precipitation at your location by the percentage of rain during the identified month desired for using the system. The gallons collected from a particular area per month is calculated by the following;

$$G = 0.6 \times P \times A \times E$$

where G is the gallons of water harvested per month, P is the monthly precipitation in inches, A is the roof footprint in square feet, 0.6 is a conversion factor that converts among inches, feet, and gallons, and E is the efficiency of the system (which is assumed to be 0.9, or 90 percent, in the absence of other information). Efficiency is important to include in a system because not all of the water that falls on a rooftop will be captured due to leakage, impact splash, first flush diverters, and evaporation. An excessively steep catchment area or an intense rainfall event may further decrease capture estimates due to gutter overflow.

Example: Designing a System

Joe Homeowner wishes to collect precipitation to water a vegetable garden covering 1,500 square feet. The OSU county Extension agent tells him he should apply an inch of water to the garden each week between June 1 and Sept. 1, and that the average annual rainfall 30 inches. Joe calculates that he will need to collect 4,114 gallons (see example calculation below) to water the garden during each month.

Water need per month = 1/12 ft/week x 4.4 wks/month x 1,500 square ft x 7.48 gal/cubic ft

= 4,114 gallons

However, during the month with the least rainfall (July or August), the garden still gets 2.4 inches of rain (30 inches per year times 8 percent, which is the percentage of average percentage of annual rainfall in July). If we assume that all this rain occurred over multiple weeks during the month (which may or may not be a good assumption during the summer in Oklahoma), then the rainfall will provide:

2.4 in x 1 ft/12 in x 1,500 sq ft x 7.48 gal/cubic ft = 2,244 gallons

where 2.4 inches is the monthly rainfall, 1,500 square feet is the area of the garden, and 1/12 and 7.48 are conversion factors.

Therefore, the total volume of rainwater that must be captured during July or August is:

Gallons used – gallons from rainfall = 4,114 gallons – 2,224 gallons = 1,870 gallons

This means that Joe will need a cistern, or cisterns, with a combined storage volume of at least 1,900 gallons. By rearranging the equation for G presented above, the catchment area needed to collect that much water in the month with the least rainfall (in this case July or August) would be:

A = 1,870 gallons / ((30 x 0.08) x 0.6 x 0.9) = 1,443 square feet of catchment

where G is 1,870 gallons, 30 inches is the annual rainfall; 0.08 or 8 percent is the monthly percentage of rainfall in July or August (from Table 1); 0.6 is a conversion factor that converts among inches, feet and gallons; 0.9, or 90 percent is the efficiency factor E; and A is the catchment area. Therefore, Joe will need to collect from a roof area with a horizontal projection of at least 1,500 square feet to cover his monthly water needs. He decides to collect from the roof of his barn, which has 1,600 square feet of roof area and is just above where he wishes to install his cistern. (Adapted from Rupp 2006).

Storage Tank

The storage tank, which is sometimes called a cistern, is the primary storage component of the system and is usually the most expensive component of the rainwater harvesting system. Material, size, and location of storage tanks are dependent upon the anticipated purposes of the collected rainwater. To enhance the effectiveness of potential collection, the storage tank must be sized accordingly. The capacity of the tank should be in proportion to the purpose estimated monthly demand, the location of later use, the monthly rainfall in inches per year, and the size of the catchment area. Cistern storage tanks come in various sizes. Table 2 shows the capacity of round cisterns with varying dimensions.

Table 1. Oklahoma average monthly rainfall distribution. (Oklahoma Climatological Survey 2002)

Month	*Percentage of Annual Rainfall*
January	4%
February	5%
March	8%
April	9%
May	14%
June	12%
July	8%
August	8%
September	11%
October	9%
November	7%
December	5%

Source: (Oklahoma Climatological Survey 2002)

Whether to have the storage tank below or above ground is a function of surrounding landscape, underground utilities, existing downspouts, cost, structural support of the surrounding foundation of soil, and aesthetic preference of the landowner. Below ground storage tanks should have manhole covers to ensure safety, yet maintain their accessibility for cleaning and upkeep. They should be sealed in order to prevent inadvertent entrance of surface or groundwater. Keep in mind the likelihood of buoyancy of an underground storage tank when empty. If the storage tank is empty and water infiltrates the ground around it, it could force the tank out of the ground.

Observe the structural support of the foundation for an above ground storage tank. The ground should be flat and able to withstand the weight of the storage tank at full capacity. It is important to consider the placement of your cistern to prevent settling resulting from improper foundation preparation. Remember, one gallon of water weighs 8.34 pounds so even with a small system of 6 feet by 6 feet, the total weight is more than 5 tons when full. This necessitates a proper

Table 2. Round cistern storage capacity for cisterns with various heights and diameters (in gallons).

Height	*6-Foot Diameter*	*12-Foot Diameter*	*18-Foot Diameter*
6	1,269	5,076	11,421
8	1,692	6,768	15,227
10	2,115	8,460	19,034
12	2,538	10,152	22,841
14	2,961	11,844	26,648
16	3,384	13,535	30,455
18	3,807	15,227	34,262
20	4,230	16,919	38,069

Source: (TWDB 2005)

foundation be installed before the cistern is put in place. If you are unsure of the capacity of a concrete foundation to support the weight of your full cistern, please consult an engineer.

To prevent algae growth and degradation due to UV rays, above ground storage tanks should be opaque, heavily tinted, painted, or have sun barriers. Storage tanks are available in a variety of materials, including plastic, fiberglass, wood, concrete and galvanized metal. They should be sturdy, watertight with a smooth interior surface, and sealed with non-toxic, waterproof materials. Special storage tank materials are required when the harvested rainwater is to be used to supply drinking water due to the possibility of leaching. Each type of material has different benefits depending on your aesthetic needs, climate, and location of the tank. Figure 1 is a general diagram of an above ground storage tank. To discourage mosquito breeding, the cistern should also have screened vents installed.

First Flush Diverters and Inlet Protection

Varying degrees of contaminant removal may be required, depending on the water's use. For most situations, a screen filter at the gutter inlet can be used to remove large debris such as leaves, sticks, or pieces of roofing material from the roof runoff. Dust and bird droppings also accumulate on roof surfaces between rainstorms. The first part of the rooftop runoff, which is called the "first flush," often contains higher concentrations of contaminants than rooftop runoff from later in the storm. This first flush may be diverted away from the cistern by a device known as a first flush diverter.

A common first flush diverter is shown in Figure 2. Water will not begin to flow into the cistern until the diverter has filled completely. A trickle drain or clean-out valve ensures an empty chamber for subsequent rainfall events. Effectively, the contaminated water is sealed off or siphoned from the next flow of rains that will enter the cistern. A general rule of thumb is to divert at least 10 gallons per 1,000 square feet of catchment area. Recommendations for minimum first flush diverter lengths are shown in Table 3.

Gutter screens and roof-washers (Figure 3) are often used in addition to first-flush diverters to prevent mosquito breeding and sediment buildup in the cistern. The proper placement for a roof washer is between the first flush diverter and the cistern. The roof washer contains a screen that will filter out large debris such as twigs and leaves. Various devices can be constructed by the homeowner or purchased commercially for this purpose. Characteristics of precipitation can affect collection such as frequency, volume, duration and intensity.

Table 3. Rainwater harvesting first flush diverter recommended lengths (Rupp 2006).

Pipe Diameter (Inches)	*Chamber Length (Inches/Gallon)*
3"	32.75"
4"	18.5"
6"	8.25"
8"	4.63"

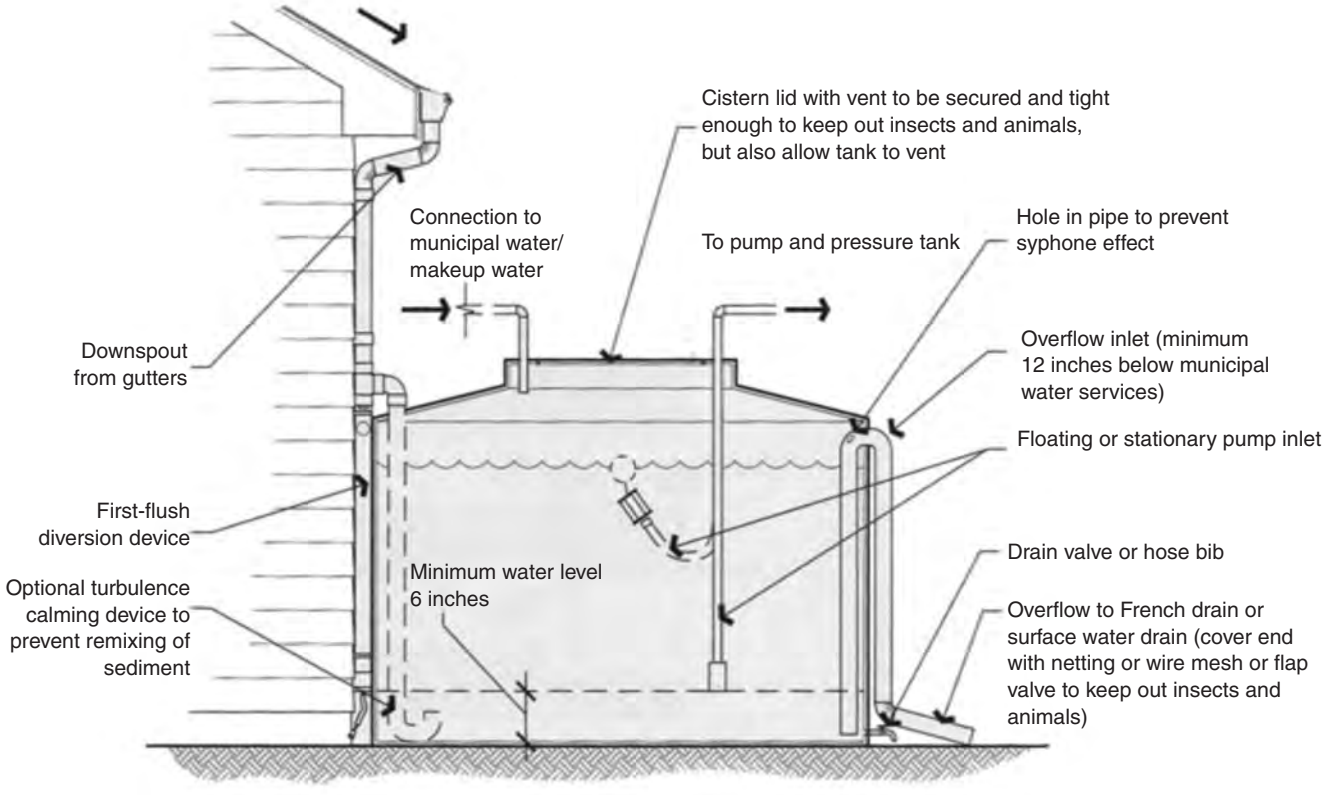

Figure 1: Above ground water harvesting system diagram. Source: (Kinkade-Levario 2004)

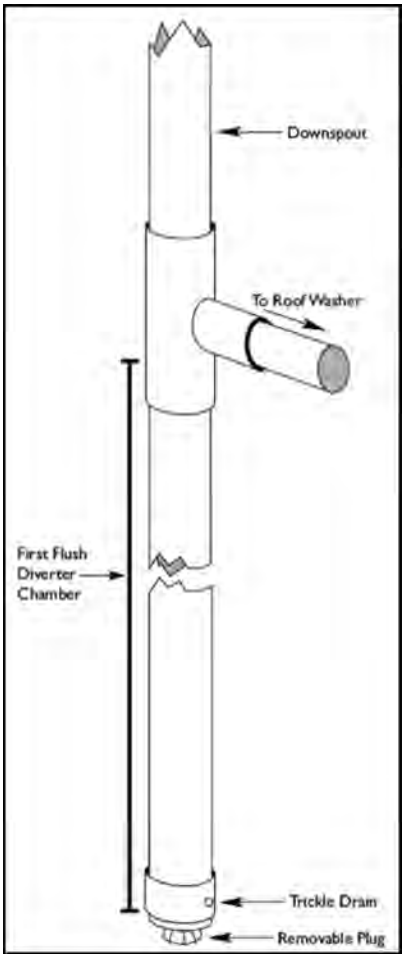

Figure 2. First flush diverter (Rupp, 2006).

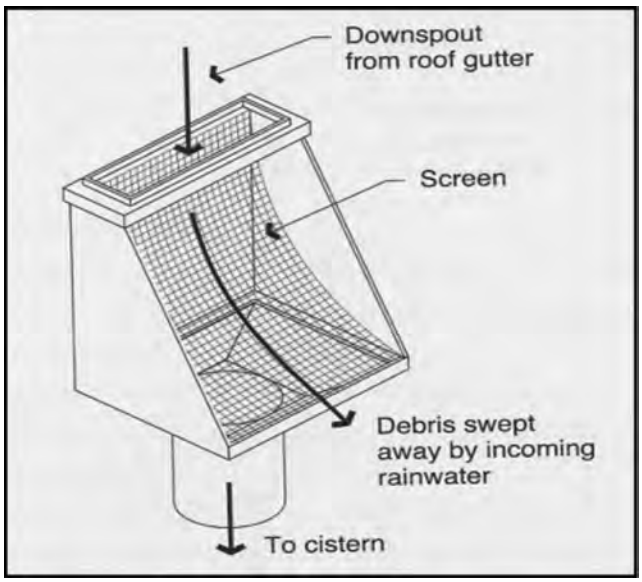

Figure 3: Roof washing system for rainwater harvesting. Source: (Kinkade-Levario 2004)

A turbulence calming device, or calming inlet, may be used to minimize bottom sediment disturbance where the rainwater enters the tank. It is another safeguard to ensure an appropriate quality of water. This device can be seen in Figure 1.

The Conveyance System

The gutter conveyance system is composed of a series of gutters, downspouts and pipes that conveys precipitation from the roof through the piping and to the cistern. The Uniform Plumbing Code (UPC) recommends that a gutter system be able to carry the runoff of the 100-year/1-hour rain event (Pushard undated). Existing gutters can be easily retrofitted to distribute more rainwater through various fixtures and to the cistern; this may require additional structural support from the building to the gutter system. The most common materials used for the gutter and piping system are PVC, seamless aluminum, and galvanized steel. The following are some general guidelines to keep in mind when designing and installing your guttering and pipe system:

- Slope gutters 0.5% (1 in/16 ft)
- Place gutter hangers 3 feet on center
- Use expansion joints in gutters 60 feet or longer
- 1 downspout per 50 feet of gutter length
- Slope horizontal conveyance pipes 2% (1 inch/4 feet)
- Horizontal conveyance pipes should have cleanouts every 100 feet
- Limit horizontal conveyance pipe bends to 45°

Source: (Sustainable Building Sourcebook 2000)

The Overflow Pipe

When the cistern has reached capacity, a bypass or overflow pipe is necessary to direct continuing water flow away from the full cistern, while also protecting the area from erosion. The overflow pipe, installed near the top of the cistern, allows excess water to leave the cistern when needed. It is required to handle the same flow as the gutter system in order to be effective. Be sure that overflow is diverted away from any building foundations, but not directly to impervious areas. The overflow can be directed to a small rain garden.

The Outlet Pipe and Distribution System

The outlet pipe, installed at least 6 inches above the bottom of the cistern, is used to draw water from the bottom of the cistern to the distribution system that ultimately delivers the captured rainwater to its desired location. A pump may be necessary to provide adequate pressure to draw water for some applications. Solar pumps are available for locations without electricity. The exact design of the distribution system will vary depending on the intended use of the harvested rainwater.

Economics of Rainwater Harvesting

The economic savings potential of installing a system depends upon the amount of water stored, the value of water at a particular location, and the intrinsic value associated by the user with using rainwater for a particular use. For instance, harvested rainwater may have an added value over tap water when used for urban irrigation because of actual

or perceived benefits of using harvested rainfall to grow their plants. Installing a system will reduce utility bills, depending on how much and to what use the water is allocated. Not all states allow rainwater to be captured and used for private or commercial use, so it is important to check state regulations before purchasing equipment.

The single largest expense is generally the storage tank, and the cost of the tank is based upon the size and the material. Costs range from a low of about $0.50 per gallon for large fiberglass tanks up to $4.00 per gallon for welded steel tanks. For those desiring professionally installed materials, costs range from $3.50 to $12 per foot of gutter, including materials and installation, in 2004. The range for pump costs runs from $385 for the low end tankless pump, to more than $1,000 for the combined price of a high-end pump and pressure tank (TWDB 2005). Buried cisterns are more expensive than those used above ground due to the larger size and multiple "moving parts." Installation of buried cisterns can also be expensive. A common cistern shared by multiple properties may result in considerable economies of scale because there is only one excavation, one tank or set of tanks, and one pump (TWDB 2005). Over time, routine maintenance and replacement of filters or other parts will be required as well.

As of March 2012, Oklahoma does not provide tax incentives concerning rainwater harvesting. However, the neighboring local and state governments of Texas and New Mexico offer various tax exemptions, rebate programs, and other financial incentives to individuals that install rainwater harvesting systems.

Rain Barrels

For residential lots, rain barrels are a simple and lower cost solution for homeowners to conserve water. The most common size of residential rain barrels is a 55-gallon barrel (as shown in Figure 4), but barrels can range from 40 to 300 gallons. Rain barrels have become more popular among the general public, and as of March 2011, pre-constructed systems are available at lawn and garden stores for between $100 to $200. If you would like to build your own there are also online companies that will sell you a do-it-yourself kit. However, with a little time and effort you can build your own system just as easily as buying one. *Oklahoma Gardening* features two episodes on "How to Build a Rain Barrel" that can be viewed at the following websites. These short episodes show the step-by-step instructions on how to build a residential rain barrel.

http://www.youtube.com/oklahomagardening#p/search/1/FeRO2MnH79M

http://www.youtube.com/oklahomagardening#p/search/0/u7joBFwn338

It is important to remember to utilize mosquito screens to prevent mosquitoes from breeding within the rain barrel. This can be done by installing a 1 mm or smaller screen at any point where standing water could be exposed to the outside environment. Rain barrels can also be painted to reflect the homeowners' sense of style (Figure 4).

Figure 4: Residential rain barrel in Stillwater, OK

Maintenance

Rainwater collection and storage facilities require a variety of routine maintenance. After every storm event while the system is in use, the first flush diverter should be cleaned out. Semi-annual maintenance should be completed in mild weather at the end of the summer and the end of winter. Since Oklahoma has very hot summers and cold winters, it is important to inspect the system to ensure that no damage has occurred due to extreme temperatures during these seasons. At least once a year, the following routine activities will need to be completed:

- Inspection and repair of vent screens.
- Removing debris from the roof, leaf guard, gutter, gutter screen, roof washer, and first-flush diverter.
- The storage tank will need to be drained and emptied of accumulated sediment every few years.
- Inspection and servicing of pumps.
- Empty the rain barrel during the winter season to prevent damage from freezing.
- The tank can be cleaned out by letting it soak in a 5 percent bleach solution and then rinsing the tank out afterwards.

Oklahoma Example

The rainwater harvesting system shown in Figure 5 is located at the Xeriscape Demonstration Garden in Edmond

Figure 5: Rainwater harvesting system capable of capturing 2,200 gallons at the Xeriscape Gardens in Edmond, Oklahoma.

that was designed and constructed by the City of Edmond in cooperation with the Oklahoma Cooperative Extension Service. The Xeriscape Garden at Bickham-Rudkin Park located at 33rd St. & Rankin was designed to demonstrate effective water management strategies within a residential landscape. Those strategies include water conservation (Xeriscape), rain water capture for use in the landscape, reduced volume and rate of stormwater runoff, and improved water quality.

Though Edmond, which is located in Oklahoma County, receives on average 36 inches of annual precipitation, it doesn't always fall during the hot summer months when it is needed by many plants. During the summer months, as much as 50 percent of the total treated water supply in Edmond is used to irrigate landscapes, and on hot, dry days that figure can reach 80 percent.

This cistern system is able to capture the runoff from a rainfall event of up to 3.6 inches or 2,200 gallons total. The total catchment area of this system is 1,100 square feet of rooftop runoff. This water is then stored for later irrigation needs. This system utilizes the rain in the cistern first and then switches to municipal water for the remainder of the water needs. The items required for the systems are listed below in Table 4 along with the total cost.

Table 4: System materials and total costs for the rainwater harvesting system at the Xeriscape Demonstration Garden in Edmond, Oklahoma.

1-½ HP submersible pump
2- 1200 gal. storage tanks
1-floating filter intake
1-pump controller with run dry protection
1-Overflow siphon
1-calming inlet
1-backup inlet valve for alternate source water
1-Tank level indicator
1-first flush diverter
1-down spout debris diverter
1-Vent cap
4-4" bulkhead fittings
4-1 ¼ bulkhead fittings
1-1 1/4 " wye strainer
2-1 ¼" brass ball valves
2-3/4" brass ball valves
All necessary pipe and fittings
Total Material Cost: $4,400
Total Labor Cost: $4,600
Total Costs: $9,000

In summary, installing a rainwater capture system, either on a large or a small scale will translate into water conservation, and may translate into dollar savings and increases in property value. Installing a rainwater harvesting system is also a great way to reduce stormwater pollution.

For Additional Resources on Rainwater Harvesting, visit us on the web at: http://lid.okstate.edu/rainfall-harvesting.

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The Oklahoma Cooperative Extension Service
Bringing the University to You!

The Cooperative Extension Service is the largest, most successful informal educational organization in the world. It is a nationwide system funded and guided by a partnership of federal, state, and local governments that delivers information to help people help themselves through the land-grant university system.

Extension carries out programs in the broad categories of agriculture, natural resources and environment; family and consumer sciences; 4-H and other youth; and community resource development. Extension staff members live and work among the people they serve to help stimulate and educate Americans to plan ahead and cope with their problems.

Some characteristics of the Cooperative Extension system are:

- The federal, state, and local governments cooperatively share in its financial support and program direction.
- It is administered by the land-grant university as designated by the state legislature through an Extension director.
- Extension programs are nonpolitical, objective, and research-based information.
- It provides practical, problem-oriented education for people of all ages. It is designated to take the knowledge of the university to those persons who do not or cannot participate in the formal classroom instruction of the university.
- It utilizes research from university, government, and other sources to help people make their own decisions.
- More than a million volunteers help multiply the impact of the Extension professional staff.
- It dispenses no funds to the public.
- It is not a regulatory agency, but it does inform people of regulations and of their options in meeting them.
- Local programs are developed and carried out in full recognition of national problems and goals.
- The Extension staff educates people through personal contacts, meetings, demonstrations, and the mass media.
- Extension has the built-in flexibility to adjust its programs and subject matter to meet new needs. Activities shift from year to year as citizen groups and Extension workers close to the problems advise changes.

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Indiana High Tunnel Handbook

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The authors assume responsibility for any errors or flaws.

Why High Tunnels?

High tunnel crop production has grown immensely in the past decade, particularly among specialty crop growers who sell directly to consumers. High tunnels (also called hoop houses) are low-cost, plastic-covered structures used for growing plants that make use of the sun's passive solar energy. The structures protect plants from weather-induced temperature extremes and adverse weather conditions (such as heavy rains, winds, and frosts), which safeguards crops for earlier planting, later harvesting, and protection from certain diseases and pests. High tunnels are often defined as unheated or passive solar greenhouses, but our survey revealed that farmers use a continuum of practices.

In this publication, we define high tunnels as poly-film-covered structures big enough to walk in that are used for growing plants — regardless of the heat system they use or don't use. Most of the discussion refers to structures without heat or with minimal heat. Hoop house is a term used interchangeably with high tunnel.

Research has shown great potential for high tunnels to increase the quality, yield, and shelf life of fresh fruits and vegetables. We developed this handbook based on a study of Indiana farmers' use of high tunnels. We learned from more than 130 Hoosier farmers about their experience growing in high tunnels through mailed surveys and on-farm interviews.

High tunnels are a new variation on greenhouses. Growers are using this low-cost technology to strengthen the viability of small-scale diversified farms that supply fresh produce for local food systems by facilitating the production of high-quality vegetables and fruits during the growing season — especially during the cooler shoulder seasons.

Farmers indicated that installing and growing in a high tunnel:

- Improved their farms' economic stability
- Improved harvest quality
- Reduced some disease problems and weed pressure
- Increased product shelf life and yield
- Protected produce from adverse weather

Overall, we found that Indiana high tunnel growers have had positive experiences. In particular, they said high tunnels helped extend the growing season and improve product quality and yield year-round. Nearly half of the growers we spoke to are now harvesting in the cooler months and planting earlier in the spring (crops such as lettuce, spinach, and kale). Another half only use the structures in summer to improve the growth and production of warm-season crops like tomatoes, peppers, and cucumbers.

Indiana farmers report annually earning a total revenue of about $1.70 per square foot of high tunnel space. Consequently, high tunnels are an increasingly important piece of farm infrastructure. However, high tunnels can be labor-intensive and high tunnel production is vulnerable to a number of weather, disease, and pest-related challenges that require advanced preparation and knowledge along with an adequate investment of time and money to manage successfully.

This publication is a resource for those who are considering high tunnel production or are relative beginners. This resource describes: selecting the right size and type of high tunnel for your operation, choosing a site location, constructing a high tunnel, determining planting dates, laying out beds, spacing plants, understanding environmental factors, monitoring soil health, and managing pests and diseases. Furthermore, this publication features information from the lived experience of farmers via survey data and on-farm case studies. Our goal is to build upon important work happening across the United States to better understand the ins and outs of producing in high tunnels.

We hope you find the handbook useful and we appreciate hearing any feedback you have. Send feedback to James Farmer (jafarmer@indiana.edu) or Liz Maynard (emaynard@purdue.edu).

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1. Opportunities and Challenges

High tunnel technology presents a unique opportunity for farmers to increase their revenue per square foot, improve the quality and yield of their crops, and extend the growing season of their operations (and thereby expand market opportunities). Hoosier farmers are using high tunnels in a variety of ways by adapting them to meet their individual needs and farm business goals.

Indiana farmers are using high tunnels as the center of their farm businesses, using them to diversify their existing operations, or using them as a way to start farming.

The Center of the Farm Business

Some farms have made high tunnel production the center of their business. These farms produce specialty crops year-round in their high tunnels. They plant root vegetables and winter greens in the late summer and early fall and harvest them through the winter and early spring. They get a head start on early tomatoes and other summer fruiting crops that fetch a price premium and continue producing into the fall. Farmers who have made high tunnel production the center of their business typically keep their high tunnel in use year-round.

Here are some advantages to centering your farm on high tunnel production:

- You can take advantage of off-season markets such as winter farmers' markets, restaurants, and winter CSAs
- You can demand a price premium for early and late produce
- You can earn year-round income
- You can attract and keep great workers
- You can grow greenhouse-specific, high-yielding varieties

This farm uses numerous high tunnels as a foundation for their specialty crop production business.

A Way to Diversify

Some farms use high tunnels to provide additional revenue streams on the side. In such cases, the primary focus might be field crops, an orchard, or field vegetable production. For these operations, the high tunnel is a side business, perhaps for their teenage kids or other family members.

Here are some advantages to using high tunnels to diversity your operation:

- You can experiment with growing high-value specialty crops such as cut flowers, delicate perennials, or berries
- You can add a unique or popular product to attract customers at farmers' markets or make your CSA more competitive
- You can add a side revenue stream (such as transplant or bedding plant production)

The high tunnels shown here are behind open fields, which marks a diversified and integrated approach to growing under cover.

A Way to Start Farming

Some farms use high tunnels as a way to start small-scale vegetable operations geared for selling produce at local farmers' markets.

Here are some advantages to using high tunnels as a way to begin a farming operation:

- High tunnels are an opportunity for beginning farmers with limited experience to increase their income as they learn and grow
- High tunnels offer a strategy for maximizing income on limited or marginal land

- The Natural Resources Conservation Service (NRCS) provides higher cost-share incentive payments to beginning, socially disadvantaged, veteran, and limited income farmers through the Environmental Quality Incentives Program (EQIP). Advance EQIP payments for high tunnels are also available.

Some farms construct DIY high tunnels while they are just getting started with the technology or when they are involved in specialty crop production.

High tunnels present many opportunities, but the decision to invest in a high tunnel should not be made lightly. High tunnels require you to significantly invest time and money to reap the benefits. The most common experience we heard from Indiana farmers growing with high tunnels was: "You get out what you put into it."

In other words, receiving a significant return on your high tunnel investment depends on how much labor and attention you give to managing your high tunnel. Farmers who invest more time and labor in their high tunnels are also obtaining a higher return. These farmers typically manage at least two tunnels and have made them the center of their farm businesses.

However, if you are already struggling to keep up with your farm business, adding a high tunnel may be a burden if you don't have the time to put into it. Likewise, if you don't have the financial resources to invest in a high-quality high tunnel, you could be at higher risk of losing your tunnel to strong winds or of experiencing structural damage that requires more time and money to fix. Be sure you are ready before you buy and know what you're getting into!

Learn from a Farmer: Harvest Moon Flower Farm

Autumn flowers bloom in front of the high tunnels at Harvest Moon Flower Farm where high tunnels have been in use for decades.

Harvest Moon Flower Farm is a small, sustainable, year-round operation in Owen County that has been owned and operated for more than 30 years by Linda Chapman. Although growing and selling flowers is their "bread and butter," they also grow a diverse assortment of herbs, vegetables, and fruit crops primarily grown for local chefs.

To round out their year on both ends, they offer a very diverse selection of garden bedding plants in the spring. For the fall and holiday seasons they create dried flower and evergreen wreaths, and other seasonal items.

Overall Management Strategy
Chapman said she is constantly cycling new flowers, herbs, salad mix, greens, and carrots in and out of the farm's six high tunnels. Some of the tunnels are heated. There is no rest period and it's very rare for there to be any bare ground that's not planted with something.

Rather than follow a set rotation of specific crops, the farm maintains a great deal of diversity and complexity in terms of plant varieties, timing of planting/harvesting, and rotations. Chapman said she follows her intuition and experience of what specific flower varieties do best in which tunnels, but she also goes by what seedlings and space she has.

Harvest Moon Flower Farm considers its emphasis on diversity to be a large contributor to its success and strength. A diversity of crops grown with knowledge and care ensures that customers get the quality the farm has become known for — be it flower bouquets, herbs, micro-greens, vegetables, fruits, plants, wreaths, or wedding florals.

"High tunnels have been fabulous for growing my business as they allowed me to start doing winter market and having income in the winter," Chapman said. "High tunnels have expanded my income substantially. They've allowed me to do weddings in November, December, and March. It's been real sweet, not to mention I get to eat really good food all winter long, which is really important, too. Efficiently utilizing our hoop houses has vastly improved the quality of what we do here and has generally allowed us to charge at least a little more than most vendors — certainly for the flowers and even sometimes for the food (our salad mix particularly). But our customers know that the quality is there and they're willing to buy it."

Greens, salad mixes, kale, and spinach flourish in the raised beds of this well-used high tunnel.

2. Considerations for New Users

In this chapter, we examine several considerations that are important when you plan to construct a high tunnel. While we discuss each factor separately, these factors are related and can affect your structure's longevity and durability, as well as your overall high tunnel experience.

In this section, we will examine:

- High tunnel selection
- Site selection and preparation
- Construction tips and considerations

High Tunnel Selection

High tunnel structures vary in shape and design. When you're selecting high tunnels, think of basic design, think of how permanent you want the structure to be, and think about how large of a structure you need for the next season and three to five years down the road.

Basic Designs

The classic Quonset tunnel is a ground-to-ground half-circle. Some Quonsets are set on higher ground posts so there are straight sides before the half-circle.

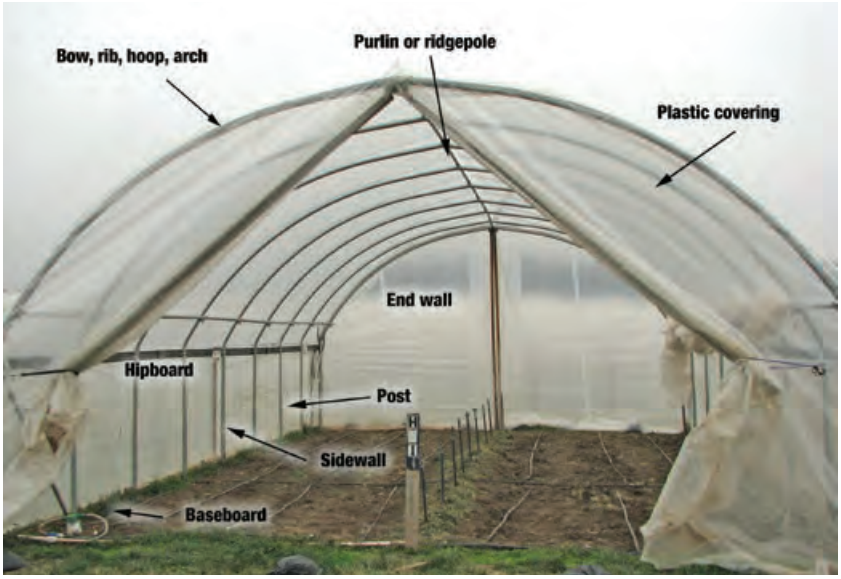
The gothic high tunnel design has a pointed roof that rises diagonally from the sidewalls to form a peak.

Single sections (or bays) of Quonset or gothic structures can be connected side-by-side to form gutter-connected multi-bay structures. These are more commonly used as heated greenhouses than unheated high tunnels.

Some multi-bay high tunnel designs are for three-season production; the structure won't support a snow load, so the plastic must be removed in the winter. These designs often cover a fairly large area; a small one might cover 1/3 acre.

Caterpillar tunnels are smaller, low-cost, less permanent structures. The plastic covering is held down with ropes, giving them the segmented appearance of a caterpillar. Lightweight hoops provide little structural support and so they are usually less than 14 feet wide. A caterpillar tunnel can be a low-cost entry point for individuals getting into tunnel production, but they also can play a role in a whole farm plan, as they do at Full Hand Farm (page 10).

High tunnels vary in structural complexity and strength. ***A.*** *A caterpillar tunnel.* ***B.*** *A caterpillar tunnel with plastic held in place by ropes.* ***C.*** *A Quonset-style tunnel with hoops made of PVC tubing and added wooden support beam.* ***D.*** *A Quonset-style tunnel with longer ground posts to create vertical sidewalls and simple vertical poly curtain end wall.* ***E.*** *A gothic-style tunnel with metal-framed polycarbonate paneled end walls, a large roll-up curtain doorway, and end-wall vents above the door.* ***F.*** *A gothic-style tunnel with roof vent.*



Anatomy of a high tunnel.

Choose the Right High Tunnel for Your Farm

When you think about investing in a high tunnel, you should carefully examine a number of things about your goals and your operation. In this section, we describe a number of important factors you should consider (and the questions you should be asking) before you decide.

General Questions

When choosing a high tunnel, you should start with some basic questions — here are six questions you should consider.

1. What Kind of Site Do You Have Available?

Consider if your site can accommodate a high tunnel and still avoid shade, sloped ground, and water seepage that would compromise the success of your high tunnel.

2. What Crops Do You Want to Grow?

What you plan to grow will affect the type of tunnel that will work best for you.

Quonset-style tunnels typically cost less, but they have very low headroom over the edge beds unless they have tall sidewalls. Low headroom would limit crops that grow tall (like trellised tomatoes). Plus, low headroom can be uncomfortable for a person who is using a walk-behind seeder or tiller near a sidewall.

The taller sides of gothic-style structures provide more useable space along the sides for working and crop production. If you plan to grow tomatoes, some trellis systems require greater height for interior and perimeter rows. Gothic-style tunnels typically have higher roll up sides, which provide better airflow over tall crops.

These trellised tomatoes are just starting to ripen. The high tunnel provides extra heat for an early crop.

3. What Seasons Do You Want to Grow In?

When you want to grow will also influence the tunnel style. Some styles work better for warm-season crops and others are better for winter growing. Choose a structure based on the season and crops you intend to emphasize.

For instance, if you're unsure that you'll have the time and energy to continue production through the fall and winter, then choose a structure and add-ons based on summer crops. If you are already busy during the summer growing season and are investing in a tunnel to extend the season, consider options that support cool-season production.

This moveable high tunnel is held in place by cables and turnbuckles connected to ground anchors. Peppers (foreground) and basil are thriving.

Key Considerations for Summer Production

If you plan to use a high tunnel for summer production:

- Be sure the structure has good ventilation and possibly fans
- Consider a design with a taller roof and that includes vents in the roof or end walls. The vents allow hot air to escape and draw cool air into the structure, which will improve airflow through side vents and out vents in roof or end walls.
- Look for designs with large doors or end walls that you can completely remove to improve ventilation
- Remember that it is more difficult to get enough cross-ventilation with very wide tunnels that just have roll-up sides

- Know that the open roll-up sides on ground-to-ground Quonset-style tunnels can expose some of crops to rain and other adverse weather

The growers have prepared the beds with peppers and tomatoes to capitalize on the heat trapped in these Quonset-style high tunnels in early spring. The tunnels have 90-degree vertical sidewalls that reach about 4 feet before the arch begins.

Key Considerations for Fall/Winter Production

If you plan to use a high tunnel for fall or winter production, then remember:

- A low structure will heat up more quickly than a taller one
- A long, narrow structure will cool down more quickly than a short, wide structure
- A gothic shape will be warmer than a Quonset shape
- Wide tunnels are easier to manage and keep heated for winter production
- Double poly covering will retain heat better. Infrared plastic is also an option to consider.
- A baseboard will protect plants on the edge beds and keep in heat. Note that certified organic production will not allow you to use treated lumber for a baseboard for crops grown in the soil — you can use untreated lumber. An alternative is to use straw bales or another insulating material to keep cold air out, particularly for quick hoops or moveable tunnels. However, using straw bales carries the risk of encouraging rodents to nest near or in the tunnel.
- If you use a heating system, your costs will be lower for structures that have lower roofs, are short and wide (vs. long and narrow), have double poly (vs. single poly), and are gothic-style designs (vs. Quonset-style).

The USDA-Agricultural Resource Service offers free "Virtual Grower" software you can use to estimate heating costs for many types of structures. Visit www.ars.usda.gov/research/software/download/?softwareid=309.

This spring mix flanked by kale has enjoyed a row cover used to trap extra heat and buffer against cold temperatures that otherwise would damage the profitable crop.

4. Do You Receive High Winds or Heavy Snows?

If you have high winds or heavy snows in your area, then remember:

- Low-profile structures with strong frame materials and extra bracing and anchoring withstand high winds better
- Poly curtain end walls are particularly vulnerable to wind damage — growers reported more problems with that type of end wall. Sturdier end wall designs fare better in Indiana, unless you have good windbreaks to protect your tunnel.
- You should purchase a structure that's been engineered to handle heavy snow loads if that's common in your area. The manufacturer will specify how much snow the structure is designed to withstand.
- If snow or ice is more than a structure can stand, then you will need to remove the snow or ice to avoid collapse, or you will need to remove the plastic covering in the winter if you are not using the high tunnel. A Quonset-style structure handles lower snow loads than comparable gothic-style structures. If

necessary, you can brace a structure by putting 2x4 boards under the ridgepole, purlins, or bows to support the structure.

- Gothic-style high tunnels typically have metal or lumber trusses that add structural stability.

High winds ripped the poly off this high tunnel.

5. What Equipment Do You Want to Use?

The equipment you want to use in your tunnel (such as tractors, rototillers, etc.) will influence the tunnel design.

When considering a tunnel:

- Make certain the end wall has a door or removable panels that are large enough for your equipment to get in and out. Poly curtain doors, overhead garage doors, sliding panels, and removable panels all provide openings big enough for tractors.
- The structure must be tall enough to operate the equipment inside.
- Remember that you can get away with smaller doors in the end wall if you do not plan to use large equipment.

This high tunnel has an 8-foot doorway to ensure accessibility for the larger equipment that might be used during the growing season.

Learn from a Farmer: Full Hand Farm

Full Hand Farm is a central Indiana vegetable farm operated by husband-and-wife team Eli Robb and Genesis McKiernan-Allen.

They currently grow about four acres of organic vegetables, which includes about 9,000 square feet of tunnel space. They make sales most weeks out of the year. They said they could make sales every week but opted to take some weeks off here and there to focus on other matters.

They use season extension, intensive farming strategies, and an emphasis on crop and market diversity to be successful.

Overall Management Strategy
At the center of Full Hand Farm's business and success is a complex rotation through four moveable and three stationary high tunnels.

Learn from a Farmer, continued

The couple started with caterpillar tunnels that they constructed themselves and are still part of their rotation.

They also have four, 20-foot x 48-foot moveable tunnels that are on skids. Each moveable tunnel has three positions or plots where they move the tunnel during the course of the year. They pull the tunnels with a winch and tractor twice a year. From April to October the tunnels cover the first position where they grow summer fruiting crops (such as tomatoes) and herbs (such as basil).

In October or November, the couple pull the tunnels off the summer crops and place them over winter crops that have already been planted. In this system, they're able to get a head start on planting their winter crops — jump-starting them before they actually need the protection of the high tunnel. That way, the winter crops are big and robust before they get covered with the tunnel.

Another benefit of this approach is that they don't have to rip out their summer crops to plant their winter crops. Often, they're still able to harvest tomatoes into the fall, as they don't need the space to plant winter crops. Another major advantage is that this system allows the couple to plant a cover crop in the third position of each high tunnel site. This creates a much longer rotation for each crop in one high tunnel site.

For instance, they only plant tomatoes once every five years on the same site. The complex and lengthy rotation reduces pest and weed pressure and ensures that any salts and minerals that build-up in the soil get flushed with a season of rain. It also allows them to have a cover crop in every rotation without losing prime high tunnel space. By rotating between the three positions per moveable tunnel and between the four moveable and three stationary high tunnels, they are able to achieve a level of diversity that has proven very successful.

The spinach in the foreground of this photo will soon be covered by the high tunnel in the back — once the tomatoes currently in the tunnel terminate and winter nears. Moveable high tunnels allow for dynamic production systems that change with the seasons.

6. What Options Are Worth Paying For?

Of course, the answer to this question is unique to your operation. However, based on survey responses and interviews with Indiana high tunnel growers, we compiled a list of high tunnel options that experienced growers commonly purchase and recommend.

Taller Structures

Many growers reported that it was worth the extra expense to invest in a taller high tunnel.

Gothic-style tunnels typically cost more, but their higher ceilings provide much better ventilation through higher end wall vents. In addition, their angled roofs shed water that condenses on the interior of the plastic, rather than dripping on plants below. It is important to avoid extra moisture as much as possible.

You can increase the height of both gothic and Quonset structures by using longer ground posts — this can offset some of the disadvantages of a simple Quonset.

Heavier Gauge Steel and Strong Structures

Many growers have had problems with high winds that damage their plastic covering — and in some cases the structure itself.

Investing in heavier gauge steel for the bows will enhance the structure's ability to handle stronger winds and greater snow loads (with obvious limitations for extreme situations). Gauge refers to the thickness of the pipe wall — the smaller the gauge the thicker the wall. For bows, the minimum suggestion is gauge 14.

Some tunnels are designed with better truss systems and more cross bracing to withstand extreme stresses. Study or ask about a product's engineering specifications to best understand what a structure can handle.

High-quality Poly

Several growers say it is worth the additional expense to purchase a higher-quality, longer-lasting polyethylene cover. They say you will gain extra seasons or years from the added investment.

Adequate Ventilation

A typical high tunnel uses sidewalls as the main ventilation (once opened). Good ventilation is critical for crop production, especially in the summer. Additional ventilation options add cost, but many growers say the expense is worth it.

Adequate airflow is important for several reasons. First, airflow helps maintain a more stable temperature at the plant level. Sufficient air flow over your plants is particularly important if you're growing tomatoes with a trellis system and winter greens — you need to get air moving over the plants even when it's cold out. Second, ventilation is critical for managing certain diseases. Finally, air movement also moves plants, which stimulates changes in their cell walls that make plants sturdier.

Here are options some growers recommended.

- **Roof vents.** Growers say roof vents are especially helpful for summer production of trellised crops like tomatoes.
- **End-wall vents near the peak (gable vents)**. Growers said these vents are especially helpful for winter growing and in the shoulder seasons when it may be too cold to open the sides but your crops need ventilation for cooling or to reduce humidity
- **Thermostatically-controlled, automated vents and/or roll-up sides**. Growers said these options are especially useful for the shoulder seasons and for times when it is difficult for someone to be on-hand to manually open and close the sides. For instance, on a cool spring or fall day, the temperatures can spike suddenly when the sun emerges on an otherwise cloudy day. Farmers without automation always need to stop what they are doing and adjust the tunnel accordingly.
- **Exhaust fans**. Farmers said exhaust fans are useful when paired with vents on the opposite wall. The combination speeds up air exchange.

In addition to investments for taller, stronger, and better ventilated structures, some growers have realized benefits from adding heaters, collecting and storing rainwater, or using moveable tunnels. The pros and cons of these add-ons are outlined below.

Heating Options

Adding heat to a high tunnel extends the growing season, speeds crop growth during cool periods and provides insurance against unexpected cold. You can use a heated tunnel for early-season transplant production, although there may be restrictions about growing plants in containers if you received USDA-NRCS funding.

In our interviews, we encountered successful operations with and without heat. If you know you want a production system that relies on additional heat, it makes sense to plan for that from the start. If you are not sure, or don't have the funds for a heater, it is possible to design a structure so that you can add a heating system later.

However, take caution: Any kind of heater, whether electric, heat, gas, or woodstove, should be designed for use in the greenhouset to reduce the risk of fire and the buildup of toxic fumes inside the structure.

Remember that a heating system will require fuel, which will be an ongoing expense. The cost of heating traditional greenhouses limits their profitability in Indiana. And some growers may not want to include heat for philosophical reasons — using biofuels, gas, or electricity adds to carbon dioxide in the atmosphere. Keep in mind that one thing that makes high tunnels attractive is that they extend the growing season without the need for adding any energy beyond the sun.

Rainwater Collection and Storage Systems

Growers that invested in systems to collect and store rainwater reported that it was worth the extra expense. Our conversations also revealed disadvantages. A typical system involves attaching gutters along the hipboards and directing the water into a storage tank. Water from the tank is pumped or flows by gravity into an irrigation system. In some operations, gutters are used to direct water away from the structure, and there is no water storage.

The pros of these systems include:

- They reduce the need for to install drainage away from tunnel.
- They reduce soil erosion by controlling the run-off.
- They provide a source of soft water, which may be helpful if well water is hard.

The cons of these systems include:

- Food safety concerns may restrict how you can use stored water for irrigating or spraying edible crops. Check with a food safety specialist.
- Algae can grow in the water tank.
- Snow and ice can accumulate in the collection system and cause problems.
- You still need an overflow drainage system for times when the tank can not hold all the rainwater.

Ventilation options. ***A.*** *This tunnel has standard louvers that are thermostatically controlled to encourage better airflow lengthwise through the tunnel.* ***B.*** *This tunnel combines automated sidewalls and automated roof vents to support summer temperature control and increased airflow.* ***C.*** *This clearstory-style roof peak allows excessive heat to escape while drawing cooler air from outside the tunnel.*

End wall options. ***A.*** *These corrugated plastic panels are a lightweight, partially-transparent material that are used for enclosing end walls.* ***B.*** *These poly end walls have oversized doors that allow for equipment access and increased airflow in and around plants.* ***C.*** *These rollup end walls have large openings. This grower installed lath fencing to safeguard against vermin.*

Moveable Tunnels

As the name suggests, moveable tunnels are designed to be moved to cover a different plot of soil, usually an adjacent plot in line with the other. There are three main movable tunnel systems:

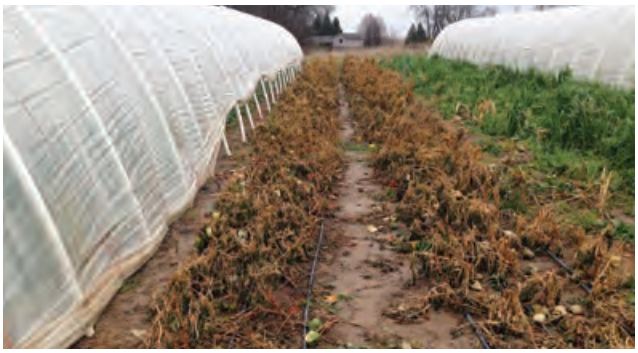
- **A rail frame system**. In this system, the tunnel frame has wheels at the base of bows and rests on a rail. Users can roll the tunnel along the rails to relocate it.

This high tunnel has a rail system frame with wheels at the base of its bows. The wheels rest on a rail, which the owner can roll it on.

- **A sled frame system**. With this system, the tunnel frame rests on a sled, which you can drag to a new location.

This high tunnel has a sled frame, which allows the owner to drag it to a new location.

- **A simple hoop system** (caterpillar). With this system, the tunnel is a simple hoop structure with no baseboard or hip board and has only a center ridge pole that connects the bows. You can move the tunnel sideways by lifting the ends of each bow on one side of the structure, rotating it 180°, and then anchoring it to the ground in the new location.



This high tunnel is a simple hoop with no baseboards (also known as a caterpillar). One end of each bow can be lifted and each bow rotated to move the tunnel to a new location.

To get full use of a movable tunnel you must carefully plan crop rotations, planting dates, and moving plans.

Most growers we interviewed had stationary tunnels. Full Hand Farm was an example of an operation that has successfully incorporated moveable tunnels (see page 10).

The pros of moveable tunnels include:

- It is easier to rotate crops to different areas of soil, which may reduce disease pressure.
- When the soil spends time uncovered, excess nutrients and salts can leach out of the soil.
- You can start cool-season crops outside in fall while the warm-season crop is still in the tunnel. When the warm season crop is finished you can move the tunnel over the cool-season crops for the winter. In the spring you can then move the tunnel off the cool-season crop to where you will plant the warm-season crop. In short, you do not have to remove one crop in order to plant the next.
- It is easier to use large equipment when ground is not covered by a tunnel.

The cons of moveable tunnels include:

- They are harder to seal along the base of the tunnel, so they are colder in winter.
- They cost more.
- They may not be as stable as fixed structures.
- Their designs are still being developed and improved, and some moveable structures can be difficult to move.
- They require additional maintenance.

USDA Programs to Finance High Tunnels

The USDA-Natural Resources Conservation Service (NRCS) assists farmers in extending the growing season for high-value crops in an environmentally safe manner through its High Tunnel System Initiative. The initiative falls under the USDA-NRCS Environmental Quality Incentives Program (EQIP).

The initiative aims to improve plant quality, improve soil quality, reduce nutrient and pesticide transport, reduce transportation inputs, and reduce energy use by providing consumers with local fresh produce.

Information about the initiative is available in the "Seasonal High Tunnel Assistance" fact sheet: prod.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_030914.pdf.

More information about the High Tunnel System Initiative is available at www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/programs/?cid=stelprdb1046250.

Program Details

The USDA-NRCS provides farmers with financial assistance for high tunnels that cover a maximum of five percent of 1 acre, or a total of 2,178 square feet. Landowners can purchase and install larger high tunnels, but the USDA-NRCS program will only pay for the first 2,178 square feet. Participants may install more high tunnels at their own expense or may already have high tunnels installed.

In addition, farmers must plant their crops in the ground or in permanent raised beds — not in containers. The high tunnels may be planned for a fixed location or planned to be portable, which means they can be rotated within or among eligible land under the participant's control.

Since water runoff from high tunnels can cause erosion, pooling, and other environmental concerns, USDA-NRCS may require you to install additional conservation measures as a condition.

Additional conservation measures include:

- Runoff management
- Filter strips
- Drain structures for water control
- Critical area planting

USDA-NRCS provides advanced payments for beginning, socially disadvantaged, veteran, and limited income farmers. The Indiana EQIP webpage has information about applying for assistance: www.nrcs.usda.gov/wps/portal/nrcs/in/programs/financial/eqip.

In some cases, high tunnel companies offer to ship a kit with an agreement that the farmer (with an EQIP contract) assign the materials portion of the EQIP payment to the company when the high tunnel is completed.

It's also important to note that state programs can change with legislation and budgets.

The USDA-Farm Service Agency (FSA) may also offer loans for farmers to help purchase materials.

3. Site Selection and Preparation

Before you invest in a high tunnel system, you'll need to carefully think about the site you want to use and you'll need to prepare the area. In this section, we'll address:

- Site considerations
- Weather considerations
- Site preparation
- Site drainage

Site Considerations

Before you place a high tunnel on your site, there are a number of conditions you should look for. Here are some of the most important:

- **Find a site with maximum sun exposure.**

You will need to orient your tunnel to avoid shade and maximize sun exposure (for both light and heat). This is particularly important if you plan for fall or winter production. To avoid shade from structures to the south, a good rule of thumb is to place the tunnel at a distance at least two times the height of the structure.

- **Site high tunnels downwind of existing tree rows.**

This will protect them from the wind. You should also keep them outside of shaded areas. Consider planting a windbreak that could help reduce the effects of wind and snow.

- **Evaluate east-west versus north-south orientation.**

A tunnel placed east-west will allow more sunlight in the structure in the winter, which is recommended for winter production north of latitude 40° north. Indiana ranges from about 39° to 42° north, so an east-west orientation is not as critical as it would be for more northern areas.

For summer production of trellised or tall crops, a north-south orientation has the advantage that crop rows oriented lengthwise in the structure will receive more uniform light on both sides of the rows, and one row won't shade the next row or rows to the north. If you have gutter-connected structures, you should orient them with the long axis north-south so that shade from the gutters doesn't stay in one location all day.

You should also consider ventilation and wind in relation to orientation. You should orient major ventilation openings (such as roll-up sidewalls) perpendicular to the direction of the prevailing wind.

- **Choose a location where the natural slope is less than 5 percent, if possible.**

A steeper slope can pose problems for drip irrigation and fertilization systems and result in uneven application of water and nutrients to your crops.

- **Avoid low-lying sites.**

Low-lying sites may collect water and often pose long-term drainage problems.

- **If you need electricity, be sure the site will work.**

If you plan on installing ventilation fans, heaters, or other electrical devices, you need to site the tunnel so that you have easy access to electricity.

- **Make sure you have easy access.**

Try to place your tunnel on a site that fits the flow of your farm. The closer it is to the main activity and main walking paths, the better. Access is one of the most important issues when siting a high tunnel. Be sure to account for flow to and from the structure for harvest, planting, and vehicles.

- **Place your tunnel near a frost-free water source.**

You will need to irrigate your crops. Be sure you can provide adequate water from a source that will not freeze.

- **Check the quality of the irrigation water at your site.**

Whether your irrigation water will come from a well, municipal source, pond, or other location, you need to be sure that it is safe and plentiful. You may need to consider ways to amend water quality.

- **Plan for the future.**

Make certain the site you choose for a high tunnel will accommodate the space and access you will need for future structures — whether you are just thinking about them or know that you will be installing them.

- **Check local zoning regulations.**

High tunnels are usually considered nonpermanent structures. Zoning was not mentioned as an issue in our survey, but restrictions can vary from place to place and may change over time.

Site Preparation

How you lay out your high tunnel is so important for later success. After you choose a site, be sure to prepare it before installing the high tunnel.

At a minimum, you should:

- **Prepare the soil before installing.**

It is crucial to prepare soil before you put up a tunnel! So, before you build, consider applying high-quality compost and organic matter, liming to adjust pH (if needed), removing perennial weeds, addressing any compaction issues, and attending to anything else you won't be able to do once the ends are framed in.

- **Run electrical and water lines first.**

If you are going to run water and electric lines to the tunnel site, do so before all the ground work is done and the tunnels location is set. Never run lines where a ground post will go.

- **Level the site well and square it out.**

Leveling the site before constructing your tunnel is much easier than afterward, and squaring it out will help with the construction process.

Site Drainage

Many growers have had to retrofit drainage around the tunnels they installed, because water flowed through their tunnel or seeped in on one or both sides. You need a way to move water away from the structure during heavy rains and snowmelt to avoid flooding the soils inside and to limit freezing in the winter.

It can be a challenge to get your drainage system right before construction, but be sure to at least develop a plan when you site the tunnel. Many farmers regretted not planning for drainage ahead of time.

Even if the site is not wet now, realize that rainwater that falls on the tunnel (and snowmelt) will need to go somewhere. If you have a 96 x 30-foot tunnel, that's 1,795 gallons of runoff water for every inch of rain. Consider installing an underground outlet or directing water to a stable area with permanent vegetation to avoid creating an erosion problem.

You may need to build up the high tunnel footprint compared to the surrounding soil to ensure that water flows away from the tunnel. That said, be careful not to build up too much on top of existing grade (less than 12 inches), because building on fill soil gives a less solid footing. If you have to, consider purchasing longer ground posts to ensure deep footings into original soil.

This photo shows why site preparation is so important for minimizing excessive drainage through the high tunnel. With the extra impermeable surface, water removal is an important consideration.

Some drainage options to consider include:

- Swales
- French drains
- Rainwater catchment or diversion systems
- Ditches

Be sure to use clean gravel around any drainage pipes you install. An added benefit of perimeter drains is that they can make it harder for tunneling creatures to get into the tunnel.

Remember that the USDA-NRCS can provide expertise and assistance with drainage issues. To find your local USDA-NRCS service center, visit www.nrcs.usda.gov/wps/portal/nrcs/in/contact/local.

Weather Considerations

Understanding the weather conditions at a potential high tunnel site is very important. But it also includes many considerations of its own. Of the more than 130 farmers we spoke with and learned from, most said weather was the greatest challenge for choosing a successful high tunnel site. Many farmers spoke about losing poly coverings to windstorms, which quickly exposed plants to frigid conditions, driving rain, and more.

In the section on siting the tunnel above, we mentioned the importance of knowing the prevailing wind direction so that the ventilation openings can be oriented perpendicular to that direction, and so you can use existing windbreaks. The construction and operation suggestions below also will help protect the structure from damage due to high winds.

When planning for the weather:

- **Use support straps.**

Install support straps outside of the polyethylene that covers the juncture where it stretches over the trusses, braces, and ribs. This will help hold the covering in place during high winds.

- **Install concrete bases for ground posts.**

Ground posts anchored in concrete are more likely to stay put than ground posts anchored in the soil alone.

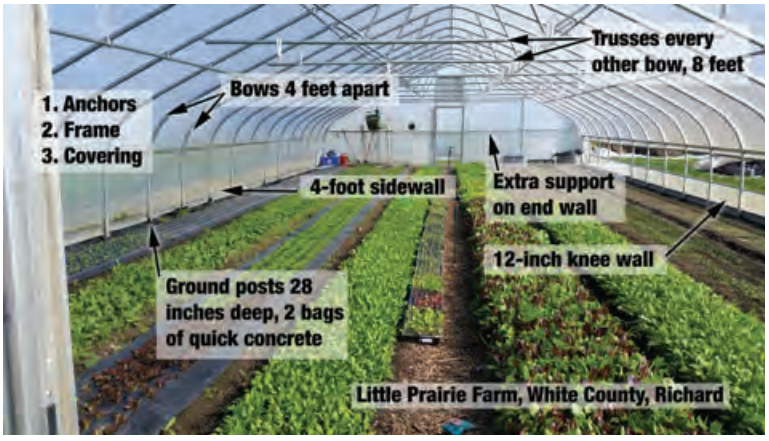
- **Consider ground anchors.**

In very high wind areas, consider ground anchors in addition to ground posts.

- **Prepare for bad weather.**

When bad weather is coming, batten down the hatches. Close and secure all doors, vents, and sides. If strong winds get into the tunnel, the structure acts like an airplane wing and tries to "take off." That puts additional stress on the plastic and structure, and often pulls posts out of the ground.

Wind can seriously damage high tunnels. These photos show a high tunnel with bent metal structures and posts pulled out of the ground. A nearby weather station recorded sustained winds of more than 20 mph and gusts of more than 50 mph. After the damage, the owner installed a vertical post to reinforce the wide curtain end wall (you can see this in the center of the bottom photo). The post also helps prevent the end wall from billowing inward during high wind.



These illustrations show the inside and outside of a structure designed for a windy location.

4. High Tunnel Construction

Whether you receive an EQIP-funded high tunnel or purchase one completely out-of-pocket, it takes time and resources to get a high tunnel up and producing. That's why it is worth giving special attention to the construction process and carefully considering decisions that can improve or hinder production, affect the structure's long-term cost effectiveness, determine the tunnel's ease of use, and influence the high tunnel's lifespan.

For starters, safety is paramount. Remember to know what's below and call before you dig. This is particularly critical in areas where underground utilities are common — think urban farms.

Indiana residents can locate their utilities online at indiana811.org. You can also call 811.

Who Should Build the Tunnel?

Should you go DIY and build your own tunnel, or should you hire someone to construct it? The short answer is: It depends.

Before you decide, consider these questions:

- **Do you really have the time to construct the high tunnel?**

The USDA-NRCS estimates that it takes 80 hours of labor to install a 30 x 72-foot high tunnel.

- **How quickly do you want to start growing in the high tunnel?**

If you want to get started as soon as possible, you may find that a contractor can install a tunnel faster than you could.

- **Do you have to wait for reimbursement from a grant or financial assistance program?**

Consider that you will be out several thousand dollars and need to get the tunnel up and constructed before receiving reimbursements in cost-share programs.

- **Do you have the needed skills?**

You need to determine if you are able to properly lay out and square the ground framing. Be certain you have the mechanical skills and physical ability needed to put the bows together and set them.

- **Do you have the help you need to see the project to completion?**

Lifting 30-foot bows and setting on ground posts is likely impossible for one person. Will you have help to get the work done and maintain safety for all involved?

- **Do you have access to necessary equipment and tools?**

See Tools (page 21) for a list of equipment and tools you might need.

Obviously, constructing your own high tunnel will save you the expense of hiring someone. Still, you may need to plant your crop soon, get your EQIP reimbursement as soon as possible, or have limited skills or help from others. If any of these apply to you, you may want to consider contracting the construction.

Only a handful of high tunnel companies in Indiana offer full service from sales to installation. You will likely need to schedule construction well in advance to ensure the high tunnel is up and running when you need it.

Other benefits to hiring a contractor to construct a high tunnel include:

- Certain warranties may require professional installation
- If materials are damaged during the building process due to construction problems, the contractor will have to cover the replacement cost
- An experienced team will generally provide a better end product that will work more effectively and last longer.
- Instruction manuals can be challenging to interpret. When you work with a contractor, they will have dealt with common issues and know how to solve them.

These photos highlight a high tunnel build at Harvest Moon Flower Farm. Many hands are needed, particularly when it's time to pull and fasten the poly into place.

Tips for DIYers

If you do decide to build your own tunnel, be sure to have everything you need before you start — tools, labor, and materials. When you receive your kit, double-check the contents and ensure that every single part is there (down to the nuts and bolts). Once you inventory the items, organize them in a way that works with the job flow. When you do, you'll want to keep the poly covering in a safe place where it won't be walked on or run over with machinery. And you'll want to keep materials dry, so tarp them until ready.

Before you begin construction create a plan or follow the one provided. The number one way to slow down the process is to do things out of order. When you go out of order, it will cause backtracking and often confusion.

Another common mistake do-it-yourselfers face is using the wrong hardware — and they frequently don't notice that until it's needed for a specific use. For example, if you have a 2 ¼-inch bolt and a 2 ½-inch bolt, the longer bolt might work for the connection that the shorter one is meant for. But when you need that longer bolt later on, you will have to backtrack and remove all the longer bolts and replace them to get the hardware you need.

Work Flow

Generally, this is the sequence a build should follow after you have performed the groundwork:

- Inventory parts
- Organize parts
- Prepare tool table or area
- Square the tunnel and set ground posts to the desired height
- Build bows (preferably on the ground and then lift them in place)
- Attach baseboards
- Set first end wall bows and construct framing (may be done later in some models)
- Set the rest of the bows, ending with the last end wall (this may depend on kit model)
- Attach side purlins
- Attach top purlins
- Attach hip boards
- Attach wind bracing
- Attach all U-channels for wiggle wire (if possible attach the end wall channels before lifting in place)
- Skin the end walls with poly or polycarbonate
- Install wind/corner baffles (if part of a kit)
- If separate from top poly, hang the sidewall curtains
- Attach roll up bars and controls
- Add wind ropes and any roll bar cradles
- Pull top poly over and attach wiggle wire or quick-lock it in
- Install doors, louvers, and any electrical devices
- Trim all excess poly materials

Pulling Poly

Although you can build the structure's frame at any point and in most weather conditions, pulling the top poly is very weather dependent. It should be calm, sunny, and warm. Mornings are often the calmest part of the day. If you pull the poly covering when it is cold, the poly will sag once it turns hot and you will need to adjust the poly again.

It is ideal to have four to six people on hand to pull the poly cover over the tunnel. It is preferable to use ropes and tennis balls to pull the poly over the frame. You can use tennis balls to tie rope to the poly to grip the plastic as you pull it over the hoop structure. This helps prevent ripping holes in the plastic.

Be sure everyone is ready and on the same page about the procedure before starting. Be careful when you roll out the poly prior to the pull. Remove any debris from the ground and roll it out slowly.

Always, no matter how subtle the wind, pull the poly into the wind. If you pull with the direction of the wind there is greater risk that the plastic will flip over itself and cause a mess that will likely damage the poly. The team that pulls the ropes attached to the poly (three to seven ropes depending on size), should be ready to shout, "Stop," if there is a snag. Another team of two or three will be on the ends and in the rafters helping get the poly over. Two people will be on the opposite sides of the rope team, fluffing and making sure the poly unravels well. They then will be the ones to attach the first side to the framing. If you use two layers of poly, it is best to pull them at the same time, one on top of the other.

Be sure to face the poly the correct way so the correct side is facing inside. If you use two layers of poly, be sure the clear or protective layer is on top.

Tools

The tools that you will need to construct a high tunnel will, of course, vary. But you can probably count on needing these items:

- Tractor with loader
- Post pounder (hand-, gas-, or air-powered)
- Laser transit
- Cordless drills or drivers
- Reciprocating saw
- Circular saw
- Clamps
- Post levelers
- Tape measures
- Reel measures
- Post puller
- Large and small sledges
- Wooden stakes
- Ropes and tennis balls (for pulling poly)
- Impact bits
- Drill bits
- Wire cutters
- Adjustable wrenches
- Pliers
- Scissors
- Tall adjustable ladders
- Eye and ear protection
- Shovels
- Mattocks
- Hoes

This photo from a high tunnel build highlights the many tools and supplies that are needed to construct the tunnel's infrastructure.

5. Planting Dates

High tunnel planting dates are determined largely by temperatures inside the tunnel, marketing plans, and particular crop requirements. For production during the cool season, day length is also a consideration.

Warm-season crops like tomatoes, peppers, and melons need air temperatures above 50°F and soil temperatures should be in the 50s or even 60s. Temperatures below 45°F or 50°F can injure warm-season crops, especially very tender crops like cucumbers and melons that require soil temperatures above 60°F. Below-freezing temperatures in the tunnel can further injure and even kill warm-season crops.

If you don't provide supplemental heat, transplanting tomatoes into high tunnels about a month before your area's frost-free date is typically about right. You may still need to protect them from frost with row covers. More tender crops could go into the tunnel about two weeks later.

You should plant most cool-season crops for late fall and winter harvests in mid- to late August or early September for the greatest yield potential. By planting this early they can grow to full or nearly full size before cold and low light slow growth to almost nothing. Early planting is especially important for crops that are harvested as full-size heads or plants. Four-week-old transplants are often used for crops like full-size kale leaves and lettuce heads. Direct-seeding is common for spinach and densely-planted salad greens.

Later plantings (through the middle of October) are possible for crops for which you harvest individual leaves or smaller plants. They will take longer to get to harvestable size and will produce less yield than earlier plantings. But, if you space out several plantings a few weeks apart in succession, it will yield a supply of fresh young leaves over a longer period than a single planting. Most crops seeded after the middle of October won't be ready to harvest until a month or more into the following year unless you harvest very tiny plants.

Some cool-season crops for spring harvest are overwintered from fall plantings. Others can be seeded or transplanted to the tunnels in late January or February. As days grow longer and temperatures increase, the crops will grow more quickly.

Crops in the cabbage family (including kale, mustards, bok choy, and others) are likely to flower after grown in cool conditions, which limits their spring harvest. The overwintered crops will make flower stalks with smaller leaves. Newly planted crops may bloom before they make marketable leaves. Customers may still purchase the blooming stems, but it is important to realize it that these are different products and should not expect them to be the same as before flowering. Early spring plantings may not be productive for many varieties of these crops. Plant some test rows before you commit to a particular variety and planting date.

Warm-season Vegetables
(tomatoes, cucumbers)

November	December	January
February	March	April
May	June	July
August	September	October

Cool-season Vegetables
(kale, spinach)

November	December	January
February	March	April
May	June	July
August	September	October

This diagram shows the general planting and harvest periods for warm- and cool-season crops in unheated structures. Yellow cells indicate planting period. Green cells indicate harvest period. Blue cells indicate potential overlap of harvest and planting periods.

6. Planting Arrangements and Spacing

Space in a high tunnel is valuable, so it is important to use it efficiently. Many growers plant on 24- to 36-inch beds separated by 12-to 24-inch walkways. Tall crops that support themselves or are supported take advantage of the vertical space, too. They can even use the space over the walkways if their trellises or support systems angle out from the bed. Indeterminate tomatoes and cucumbers are good examples of crops that use vertical space.

Intercropping smaller, short-season crops with larger, long-season crops is another way to intensify production. Growers are experimenting with intercropping to find best practices. For example, spring-sown beets and lettuce can be grown along the edge of a bed of transplanted tomatoes and will be harvested before the tomato plants get large.

Bed size and arrangement influence work efficiency and the effective growing area. For a given bed and alley width, long-ways beds will provide more plantable square feet. You can use the percent of total square footage in a tunnel available for planting to compare different bed and alley arrangements. For crops planted in single or double rows on beds, the amount of crop space is sometimes expressed as linear bed feet. Since you can fit more beds in a tunnel if they are narrower, using narrow beds will create more linear bed feet. See Table 1.

Long beds are also easier to prepare with equipment, because there is a longer run before you need to turn around the equipment. Long beds may also be more efficient because at least one alley way will be close to the center of the end wall, which will make it easy to move harvest bins and larger equipment the length of the structure. Many high tunnels are planted in long beds for these reasons.

You may also use crossway beds, which can be the preferred choice in some cases. For instance, in an east-west oriented tunnel, it may be desirable to grow a crop of tomatoes in north-south beds so the shade from one tomato row moves around during the day instead of always falling on the next row to the north.

These images show common bed arrangements and spacing. ***A.*** *A longways bed or row on 4- to 6-foot centers.* ***B.*** *A longways bed or row on 4- to 6-foot centers with two rows of strawberries.* ***C.*** *Beds that are 2.5 to 3.5 feet across with densely planted kale, lettuce, and other greens, with narrow walkways between the beds.* ***D.*** *Crossway beds with a variety of crops in a fairly wide high tunnel.*

In addition to the amount of square footage for planting and work efficiency, consider how much space you need to move and work in the alleys and how much space you need between the end of the crop and the end walls. Tunnel corners are often underused because they are difficult to get to. Consider planting a perennial herb or plants that provide habitat or food for beneficial insects in such areas. Locating alleys along edges and end walls can be helpful, because those areas are typically cooler and wetter, which make them less desirable for plant growth.

Table 1. Examples of plantable area and linear bed feet for various long and crossway bed arrangements in a 96 x 30-foot high tunnel.

Bed Width	Number of Beds	Alley Width (feet)[1]	Plantable Area (sq. ft.)	Plantable Area (%)	Linear Bed Feet
Long beds (90 feet long with a 3-foot alley along each end wall)					
2.5	8	1	1,800	62.5	720
3	7	1	1,890	65.6	630
3.5	6	1.25	1,890	65.6	540
3.75	6	1	2,025	70.3	540
Crossway beds (27 feet long with a 1.5-foot alley along each side wall)					
2.5	28	1	1,822	63.3	729
3	23	1	1,863	64.7	621
3.5	19	1.25	1,796	62.3	513
3.75	19	1	1,928	66.8	513

[1]The number of alleys is always one more than number of beds.

The microenvironment varies in the tunnel, so when growing multiple kinds of crops, place crops where they are best adapted (to the extent that's possible). The edges of the tunnel will be colder, especially in the winter, so that is the place for the most cold-hardy crops like spinach and kale. Edges will also be windier when the sides or end walls are open. Keep in mind that every tunnel seems to have wet spots — whether it is just a low area, or along an entire side or end where water seeps in after rain.

Some areas in the tunnel may receive more shade than others, and tall crops will shade shorter ones to the north. Put tall crops on the north side of the tunnel, unless there is something that you specifically want to grow in the shade, or unless the tunnel is not tall enough on the side. You can also plant tall crops up the middle to give them the maximum space to climb in the highest part of the tunnel.

Understanding the microenvironment is also important for pest management. Mites tend to appear first in hot, dry areas; root diseases in wet areas; foliar diseases in locations where the humidity remains high due to wet soil and/or shade.

Poorly drained areas in tunnels contribute to high humidity and increase the risk of plant diseases.

7. Environmental Management

Air and soil temperature, relative humidity, and light all influence plant growth and, to some extent, you can manage them in a high tunnel. Air temperature is the most common focus.

Understanding the factors that influence air temperature will help you to manage it. hen sunlight enters a tunnel, some of the radiation hits the soil (and other objects in the tunnel), and then gets reflected back toward the sky as longer wavelengths. The tunnel's plastic covering does not permit infrared wavelengths to pass through as easily, so these wavelengths are trapped inside the tunnel, which warms the air.

On a sunny day, the air temperature inside a tunnel can quickly increase to tens of degrees warmer than it is outside. On a cloudy day the difference may only be a few degrees. After the sun goes down, the tunnel loses heat through the plastic covering and through gaps in the covering. The rate of heat loss depends on how much colder it is outside than inside and how windy it is. The greater the temperature difference between the inside and outside of the structure, the faster the inside temperature will drop. The windier it is, the faster the tunnel will lose heat.

The tunnel's surface area compared to its volume also makes a difference. The more surface area for a given volume, the faster the heat loss. A long, narrow tunnel has more surface area per cubic foot of space, which will cause it to cool down more quickly than a wider tunnel that encloses the same cubic feet.

Some of the daytime radiation that hits the soil and other objects in the tunnel gets directly absorbed by (and warms) those objects. After the sun goes down and the air starts to cool, the soil also cools and loses its heat to the air. In this way, the soil acts as a heat storage system, or heat "sink." The heat that the soil releases overnight can keep the air temperature inside the tunnel higher than the outside when there is a layer of insulating material.

A single layer of plastic does not insulate well. The overnight low temperature inside a tunnel covered with just one layer of plastic can easily drop to the outside temperature. Row covers and/or inflated double layers of plastic are better insulators and will increase air temperature in the high tunnel on cold nights.

On sunny days in spring and fall and on most days in the summer, the air temperature inside the high tunnel gets too high for optimal plant growth. The solution is to ventilate — let cooler outside air pass through the tunnel. Depending on the structure, this may mean rolling up sidewalls, opening end wall doors or vents, opening roof vents, or moving plastic to create openings.

In spring and fall, you may need to do this daily. In summer, the vents often are open all the time except during severe weather. You can install thermostatically controlled motors to open and close vents and sidewalls. However, whether the expense is worth the savings in time will be different for each farm operation.

In greenhouses, thermostatically controlled vents in end walls are often paired with fans in the opposite end wall to increase airflow. Some high tunnels also have this option, and it can reduce the need to manage sidewalls early and late in the season.

It's important to note that ventilation alone (with or without fans) will not reduce the temperature inside the tunnel below what it is outside. It will always be a few degrees warmer inside the tunnel.

In locations with warm, sunny summers, farmers also use shade cloth for temperature management. The cloth reduces the amount of sunlight that enters the tunnel, which reduces the temperature. But the shade also reduces the light that plants need for photosynthesis, so there is a trade-off. For tomatoes in Indiana, 30 percent shade is typical, and this is likely a good level for other summer crops as well.

Another strategy for reducing summer temperatures is to reduce the number of objects in the structure that absorb heat. Light-colored mulches and ground covers reflect more radiation, and heat up less, than dark-colored mulches and ground covers. Thus, light-colored mulches can reduce heat buildup in the summer. Because many summer crops benefit from soil warming early in the season, many growers use a dark-colored or IRT plastic mulch in the row to warm soil near crop roots, and a light-colored mulch or ground cloth between rows. As the plants grow, they shade the dark mulch and reduce its warming effect.

In spring and fall, temperatures in the tunnel drop below optimum, and in winter they may remain below optimum for weeks at a time. At these times, the strategy is to maximize heat storage in the tunnel and reduce heat loss. Common practices include using row covers and additional insulation around the base of the tunnel. A double plastic covering is helpful but not essential.

Row Covers

Spun-bonded, lightweight fabric insulates better than a single layer of plastic. This material is used just above the crop to provide an insulation layer that traps heat from the soil near the crop and slows heat loss from the tunnel. You may place the fabric over individual rows or beds, over multiple rows, or over the entire width of the tunnel. You can support the fabric with wires or small hoops, or in some cases, you can drape it over the crop like a blanket.

Fabrics are available in different weights. Heavier weights provide more insulation but also block more light. Most growers use a mid-weight cover and double it when temperatures get very cold, but growers have had success using lightweight covers, too.

You can remove the cover during the day and put it on as temperatures drop in the evening. This allows the most light to plants and the most soil warming. Growers also have success leaving covers on both day and night during the coldest weather.

Experienced growers follow guidelines for placement. For example, if the temperature is below 25°F, they use one layer; if is below 20°F, they use two layers, depending on the crops. For cold-tolerant crops in winter production, row covers are not meant to prevent crops from freezing. Crops adapted to this production system can withstand freezing, thawing, and refreezing. It is important not to handle, harvest, or jostle crops while they are frozen because that will injure them and reduce their marketability.

The previous discussion has been about using row covers on cold-hardy crops growing in the winter. For frost-sensitive warm-season crops, row covers also protect against cool temperatures and freezing. For warm-season crops, temperatures should not fall below 50°F for any length of time. The longer there are low temperatures and the lower the temperature, the greater the likelihood of chilling injury, a physiological injury that slows growth and sets the plant back. Frost injury can occur if the temperature drops below 32°F in the tunnel. When protecting crops from frost, it is best to support the cover above the crop, rather than to rest it on the crop. If you were to rest the cover directly on the crop, the plant is likely to freeze at the points it contacts the cover.

Growers also use clear plastic that is supported on rebar, conduit, or another structure to create tunnels within tunnels. When left in place during the day, this mini-tunnel traps additional heat, and the air above the small tunnel acts as an insulating layer. Temperatures inside the smaller tunnel can rise quickly on a sunny day, so it is important to monitor and open them if it gets too hot. Some growers use clear plastic over-row covers on the coldest nights.

Row covers protect crops from low temperatures inside the high tunnel. They can be supported above crops on wire hoops or other lightweight supports, or, if it won't damage the plants, laid over the crop like a blanket.

Controlling Humidity

Relative humidity greatly influences plant diseases. High humidity promotes many fungal diseases, and when humidity is high enough that water drops condense and remain on leaves, certain diseases are even more likely.

Relative humidity depends on the amount of moisture in the air and the temperature. For a given amount of water vapor in the air, as temperature drops, relative humidity increases; as temperature rises, relative humidity decreases. A 24-hour graph of relative humidity in a high tunnel illustrates this: it drops as the sun rises and temperature goes up, then increases again at night as the temperature drops.

Ventilation is the primary means of reducing relative humidity in a high tunnel. Row covers can trap moisture close to the plants, so removing them periodically can reduce humidity near crops in the winter.

Supplemental Heat

Although the definition of a high tunnel usually includes the word "unheated," some producers provide heat for emergencies to prevent freezing warm-season crops, or to minimally heat the structure to increase crop production during the winter.

A complete discussion of heating greenhouse structures belongs in another publication, but we will briefly consider it here.

Growers report using portable, unvented propane heaters that "burn clean" for emergency heat. We don't recommend these because exhaust fumes from these heaters contain materials that are toxic to plants and humans and may build up to harmful concentrations if the heater is not exhausted out of the tunnel. Without a fresh air supply, the burners may use oxygen fast enough to deplete the supply in the tunnel to dangerous levels.

Propane and natural gas-fired unit heaters are common in standard greenhouses, and in high tunnels where they are used for minimal heating in the winter. Growers also use furnaces that burn wood or corn. Few Indiana growers use geothermal heating systems.

Minimally heated structures are typically kept above 28-32°F. This speeds cool-season crop growth in the dead of winter, and it allows less hardy crops (like lettuce) to survive, which increases yield. Growers also supply heat to get a jump-start on warm-season crops. Heating the soil is an efficient way to provide heat in a high tunnel for winter crops or in the early season for spring crops.

There are a variety of systems you may use: you can bury water tubes below tillage depth, and pump water through them to heat the soil; you can add perforated pipes in the soil and force warm air through them; or you can add heating cables in or on the soil. Roots grow faster in warmer soil, the soil heats the air, and the tops grow faster because of both improved root growth and increased air temperature.

Learn from a Farmer: Silverthorn Farm

Silverthorn Farm is a small, diversified vegetable and small animal farm on 120 acres in northern Clinton County, near Rossville, Indiana. The farm is owned and operated by Nate and Emily Parks and has been in Emily's family for generations. Nate was also lucky enough to grow up on a highly diversified farm. Today, they farm on about 20 acres of the family property to produce meat, eggs, and more than 40 different types of vegetables with more than 200 varieties.

Overall Management Strategy

High tunnels are at the center of Silverthorn Farm's business. They rotate summer fruiting crops, herbs, and winter greens crops through five tunnels. They plant summer fruiting crops in early April, harvest them through September, and plant and seed winter crops in mid-September.

They recently invested in a very large structure that was designed for a commercial greenhouse and will provide 20,000 square feet of growing space! This structure will be heated, which will allow them to raise seedlings, create a retail space for on-farm sales, and grow potted herbs in addition to succession plantings of winter greens and herbs. The gas heater will allow them to plant as early as February to get a head start on summer fruiting crops.

They say that using organic growing methods and extensive rotations between five tunnels helps them keep pest and weed pressure to a minimum. In addition, their emphasis on diversity provides an impressive array of produce year-round that has increased their customer base and reputation with area restaurants. Finally, their success derives from an innovative, flexible, customer-focused, and web-based CSA model to distribute their products.

This is a gutter-connected structure from Silverthorn Farm — there are three high tunnels coupled together. Emily and Nate Parks grow lettuce, chard, onions, mixed greens, spinach, and several other crops in this structure. They also have planting tables for starts.

8. Soil Management

Well-managed soil in high tunnels will provide an environment where roots grow easily; plants benefit from interactions with soil microorganisms; mineral nutrients are present and available in sufficient supply for healthy plant growth; and crop pathogens, weed seeds, and invertebrate pests don't reduce yield or quality.

Roots need soil with plenty of pore space for air and with little compaction. Intensively cultivated soils in high tunnels are prone to compaction because of repeated traffic — from feet or machines. In addition, tillage that creates smooth, uniform seedbeds for direct-seeded crops can beat the soil into small particles, which destroys the mix of larger and smaller particles that form the basis of good soil structure. Even before crops are grown, the soils in many high tunnels were already compacted during construction when machinery may have graded the soil or moved parts into place.

You can reduce soil compaction in the crop root zone by planting on beds and limiting traffic to alleys between beds. The beds may be raised or flat and they may be kept from season to season or remade periodically.

You can also create a compacted layer if you repeatedly till to the same depth, especially with an implement like a rototiller. Some growers use broadforks, power harrows, or spaders to avoid this problem. Another solution is to break up the compacted layer with a deep shank that you pull through the soil.

You can also help to reduce the negative effects of compaction by maintaining or increasing soil organic matter. Deep rooting cover crops can also help alleviate compaction. You can add organic matter in the form of: mulches for weed control that you work into the soil (such as straw, dead leaves); composts that supply nutrients; cover crops; and crop residue if you do not remove it from the tunnel as a disease management practice.

Managing soil nutrients in a high tunnel is similar to managing nutrients in the field in a dry climate: minerals added to the soil are either taken up by plants or stay in the soil unless you irrigate beyond what the crop needs to leach the minerals out. Over time, minerals can build up high enough that crop growth suffers.

You may be adding minerals through fertilizers, composts, mulches, or other soil amendments. You can also add minerals with your irrigation. If you irrigate with hard well water, the minerals in the water include calcium and magnesium. Over time, these minerals increase soil pH. As soil pH increases greater than 7, some plant nutrients become unavailable for crop uptake and deficiency may occur.

This image shows the previous season's tomato remnants (left) and a well-established cover crop. These tunnels will be flipped to cover the center areas that are currently not under cover.

Soil Testing

Annual soil tests that indicate nutrient content, pH, soluble salts, and organic matter will help you determine whether minerals are building up. You can also use the results to estimate how much and which nutrients you should add to ensure a healthy crop.

Irrigation water tests that determine the mineral content of your irrigation water are also helpful. From these tests you can determine how much of what minerals are added with each inch (or gallon) of irrigation, and these values can go into the tunnel's nutrient budget. The tests will also alert you to high alkalinity or sodium levels in the water that, if not addressed, can reduce soil quality over time.

Usually, growers add nutrient sources and mix them into the soil when they prepare for planting. For crops that will be grown for three months or more in the summer (like tomatoes or peppers), growers often supply additional nutrients several times during the season (especially nitrogen and sometimes potassium).

When growers use drip irrigation and soluble fertilizers, it is common to supply a little fertilizer through the drip irrigation system a few times a week or even with every watering. With a fertigation system like that, it is important to tally up all the added nutrients over

the course of the season and to confirm that the total matches what the crop needs. Otherwise, it is easy to over-apply and build nutrient levels up so high that they limit plant growth.

If the soil has adequate nutrients to support a crop, then you can maintain fertility by adding nutrients each crop cycle to replace what the crop will remove when it is harvested. Table 2 provides estimates of major nutrients contained in each 100 pounds of a crop harvest. This represents the nutrients that you would need to add in order not to deplete the soil.

If you remove the entire plant from the tunnel as well as the harvested portion of the crop (for example, tomato plants), then you should also consider the nutrients contained in the plant. As soil fertility builds up over years by adding organic matter, the soil will be able to supply more nitrogen each year, and the need for amendments with large amounts of nitrogen should decrease.

Table 2 also estimates the amount of nitrogen per 1,000 square feet that crops typically need from fertilizers and soil amendments (if the soil does not have a build-up of nitrogen-supplying potential).

Determining how much of what soil amendment or fertilizer to apply in a high tunnel involves estimating how much the crop will need, how much the soil will supply, and how much the harvested crop will remove. You can use leguminous green manures to supply nitrogen to the next crop, and you should include their contribution when you figure out what amendments your soil needs. Soil testing for major plant nutrients, pH, and organic matter is an important tool for maintaining soil fertility.

You can mitigate nutrient buildup in a high tunnel by repeated heavy irrigation to leach away soluble nutrients. Or, you can remove the plastic covering and leave it off long enough to allow several inches of rain to leach excess nutrients. Tunnels that are designed to easily move from one spot to another provide another way to avoid nutrient buildup.

In our survey of Indiana high tunnel growers, high soil phosphorus levels were a common problem. This doesn't usually harm plants, but it can lead to environmental pollution if the phosphorus leaches or moves away on soil particles.

You can test soils for the level of soluble salts, which measures the quantity of dissolved salts that can inhibit plant growth if too high. Many of the salts come from fertilizers or irrigation water and can build up if nutrient applications are excessive. A white crust may be visible on the soil surface, which raises concern that salts might be injuring plants. Other researchers have measured soluble salt levels associated with this crust in high tunnels and found it does not indicate a build-up of salts that will harm plant growth. In the soil samples we took from 20 Indiana high tunnels, high salts were not a problem.

Managing the biological component of soil is the area where we have the least research-based knowledge. In general, biological activity in the soil indicates soil health, and you can promote biological activity by adding organic matter and maintaining aeration and good drainage. Some labs offer soil tests that measure the biological aspects of soil health. Conducted over a period of years, these tests help you monitor trends in biological activity.

Indiana Soil and Water: How to Understand and Interpret Soil Health Tests (Purdue Extension publication AY-366-W) describes the tests and discusses their use in agronomic crops. It's available from the Education Store, edustore.purdue.edu.

The most specific recommendations about managing the biological components of soil relate to managing plant diseases that survive in the soil. These diseases can be especially problematic in high tunnels, because growers often plant the same susceptible crop there year after year due to its high value (such as tomatoes). This practice provides no chance for the pathogen to die off and break the disease cycle.

Managing diseases that survive on crop debris or in the soil involves accurately diagnosing diseases, rotating to crops not affected by that disease, and following strict sanitation practices. A soil may become so infested with disease that you cannot profitably grow a crop. In these cases, some growers choose to grow crops in containers of growing media and discard the media after a season or two. The disadvantage of growing in containers is that the system does not take advantage of the biological, chemical, physical relationships that can develop between plant and soil — and this method does not qualify for USDA-NRCS High Tunnel Initiative programs.

Indiana high tunnel growers who responded to our survey said that adding compost was the most widely used soil fertility practice (61 percent), followed by organic fertilizers (52 percent). These soil amendments are probably why soil phosphorus was very high in several tunnels. Composts and many organic soil amendments have a higher proportion of phosphorus to nitrogen than plants require. If you apply the

amendments to supply enough nitrogen, you will also add more phosphorus than the crop can use.

The survey also found that 30 to 40 percent of respondents used foliar feeding, cover crops, and synthetic fertilizers to supply nutrients. Not quite a quarter of respondents used fertigation and other methods. Several who used fertigation mentioned it was an easy way to evenly distribute nutrients in the cropped area.

An example of a fertilizer application system that has been integrated with a drip irrigation system that is commonly used in high tunnels.

Source: Adapted from D. Warncke, J. Dahl, and B. Zandstra. 2004. Nutrient Recommendations for Vegetable Crops in Michigan. E2934. Michigan State University Extension, Lansing.

Table 2. Estimated nitrogen requirement and amounts of nitrogen, phosphorus (as P2O5), and potassium (as K2O) removed in harvested portion of selected vegetable crops.

	Crop Nitrogen Requirement	Nutrients Removed in Harvested Portion of Crop		
Crop	**N** (lbs. per 1,000 ft^2)	**N** (lbs. per100 lbs. of crop)	**P_2O_5** (lbs. per 100 lbs. of crop)	**K_2O** (lbs. per 100 lbs. of crop)
beans, snap	0.92	1.20	0.12	0.55
beets, red	2.30	0.18	0.11	0.39
broccoli	3.21	0.20	0.06	0.55
cabbage, Chinese	2.75	0.35	0.08	0.34
cabbage	3.21	0.35	0.08	0.34
carrots	2.30	0.17	0.09	0.34
cauliflower	3.21	0.33	0.13	0.33
celeriac	3.44	0.20	0.13	0.33
cucumber, slicers	1.84	0.10	0.06	0.18
eggplant	2.75	0.22	0.08	0.26
greens, leafy	2.30	0.24	0.10	0.30
kohlrabi	3.21	0.30	0.13	0.33
leek	3.44	0.20	0.13	0.24
lettuce, leaf, or bib	2.30	0.24	0.10	0.45
lettuce, romaine	3.21	0.24	0.10	0.45
market garden	3.21	0.32	0.14	0.28
muskmelon	2.30	0.42	0.10	0.55
onion, green	2.98	0.25	0.13	0.24
pak choi	2.75	0.35	0.08	0.34
parsley	2.30	0.24	0.09	0.64
parsnip	2.30	0.17	0.16	0.45
pea	0.92	1.00	0.23	0.50
pepper	2.30	0.20	0.07	0.28
potato	4.13	0.33	0.13	0.63
radish	1.15	0.15	0.04	0.28
spinach	3.90	0.50	0.14	0.60
squash, summer	1.84	0.18	0.11	0.33
sweet potato	1.38	0.265	0.12	0.64
Swiss chard	2.30	0.18	0.06	0.44
tomato	2.75	0.20	0.04	0.35
turnip	2.07	0.17	0.06	0.23

9. Pest and Weed Management

To effectively manage pests, you need to be aware of likely pests, correctly identify pest organisms, understand pest life cycles, learn to efficiently scout for problems, and use a variety of management strategies to reduce damage to acceptable levels.

Insect and Disease Management

Plan your insect and disease management before planting the crop. Learn what problems are likely by reading and talking with others. Choose management practices that you want to use and prepare to implement them. Develop a plan for weekly crop scouting and a way to record what you find. If unknown pests or diseases show up, identify them and learn about management practices. When pest pressure is high enough to warrant action, implement your control strategies. Then, note how well they work so you can make adjust them in the future.

As one grower notes:

> "I always anticipate the arrival of aphids on certain high tunnel crops in the late winter and early spring. So, I order ladybugs and parasitic wasps by mid- February to get on top of an outbreak before it gets critical."

Cultural pest management practices may also help in high tunnel production. Of the common cultural practices, crop rotation might be less effective in tunnel production because there are just a few crops that produce the biggest profits. Moveable high tunnels or structures that you can move to another location may help.

Managing the environment can be important for reducing disease pressure. It is important to vent the tunnel to bring in outside air, dry off leaves, and reduce humidity — even in winter. It also helps to remove row covers in winter (when possible) or consider planting arrangements that promote good airflow to reduce humidity.

You should also assure the tunnel has proper drainage so rainwater doesn't seep into the tunnel and keep the soil saturated. Adequate drainage will reduce humidity and diseases caused by soil organisms that proliferate in wet soils.

Devote your attention to sanitation. Remove crop residue from the structure, clean and sanitize hardware and materials that contact plants, and keep weed mats free of plant residue. All these practices can reduce inoculum that starts new disease cycles.

To help manage insects, provide habitat for the natural enemies of pests. To do this, plant appropriate plants inside and/or outside the structure. In particular instances, you can purchase and release natural enemies.

Natural pest enemies include parasitic wasps, ladybug larvae and adults, lacewing larvae, minute pirate bugs, and predatory mites. Remember that the effective use of natural enemies requires understanding when and how to use them — a thorough discussion is beyond the scope of this publication, so consult knowledgeable practitioners and be prepared to learn as you go. About 40 percent of Indiana growers remove insects by hand to control them.

You may need to resort to pesticides to control diseases and insects in high tunnels in both conventional and organic production systems. For current, crop-specific pest control information, refer to the *Midwest Vegetable Production Guide for Commercial Growers* (Purdue Extension publication ID-56) available at mwveguide.org, or contact your local university extension specialist.

In some situations, you can protect crops from insects by using row covers or netting. Research underway at Purdue and elsewhere is investigating how netting can exclude insects from the entire tunnel or keep beneficial insects inside the structure.

Rodents have proven to be serious problems in high tunnel production. They may eat seeds, leafy greens, or root systems underground. They can destroy entire plantings of winter or spring crops.

Mice and voles seem to be the most common. Current control practices include trapping and killing and using bait stations. Bait stations are regulated as pesticides, so you must use them following the instructions on the product label. If you use bait stations around a crop, the label must explicitly state that the product may be used in that crop.

You should also manage the habitat outside of the structure to make it unfavorable to these creatures and try to discourage them from setting up home in your tunnel. It has been suggested that you should construct the tunnel so rodents cannot enter. One researcher from Connecticut suggests burying hardware cloth 18 inches below the soil line around the edge of the tunnel to prevent voles from entering.

Weed Management

Planning to manage weeds begins before you build the tunnel. Choose a site without perennial weeds like Canada thistle, horsenettle, or quackgrass; or manage those weeds before you construct the tunnel. Refer to weed management guidelines for the particular perennial weed problem.

Take care when you bring in soil, compost, mulch, or cover crop seed. You must avoid importing weed seeds and perennial plant parts such as underground stems, rhizomes, stolons (as from quackgrass), or roots (as from Canada thistle). All these parts and seeds have the ability to sprout new plants.

Create a stale seedbed before planting by preparing the soil, wetting it, and allowing a flush of weed seedlings to emerge. Kill those seedlings while they are small with very shallow cultivation, flaming, silage tarps, or another method that does not disturb the soil much — that way you will not bring new weed seeds to the soil surface. Be careful with flame weeding near polyethylene, straw, silage tarps, and other flammable materials.

Use dense crop plantings to out-compete weeds. This will help to keep weeds small.

Use drip or targeted overhead irrigation to wet soil only near crops; fewer weeds will grow in areas that are not irrigated.

Remove weeds when they are small to minimize competition with the crop. Don't let weeds go to seed or that seed will provide weed problems for years to come. If weeds do flower, remove them from the structure before seeds can mature.

Design your bed's shape, size, and planting arrangements so you can efficiently use your weeding tools. You should explore the weeding implements that are available, learn and/or teach workers how to use them, and keep them sharpened. In our grower survey, 20 percent said they used machine cultivation, 70 percent used hand hoeing, and more than 80 percent used hand-pulling. Around 10 percent used flaming implements.

Many growers use mulches to control weeds. In the planted row, opaque plastic mulches or woven weed mats are common. Between rows, woven weed mats or organic materials (like straw, leaves, wood chips, and cardboard) are used. Mulches also help maintain soil moisture and shade the soil in the summer.

Pay attention to the source of the mulch, and avoid materials that:

- Could present food safety hazards (including improperly composted materials)
- Be a source of weed seed (such as weedy straw)
- Contain damaging herbicide residues (such as grass clippings from areas treated with broadleaf herbicides)

Under certain conditions, you may apply herbicides inside a high tunnel. About 10 percent of surveyed growers use herbicides. A thorough discussion of herbicides is more involved than we will provide in this document. To learn more about herbicide options, contact a horticultural weed scientist from your state's extension service.

10. Irrigation

An irrigation system is necessary for high tunnel production. During the summer, full-size crops will require more than 1 inch of water per week — or more than 1,800 gallons in a 30 x 96-foot structure. Crops require less in winter.

Growers commonly use well water, but some use a municipal or other public water supply, surface water from a pond or stream, or runoff from the high tunnel roof. Always test water sources to ensure they are suitable for irrigation. Depending on the crops you grow, the size and nature of your business, and the irrigation system you use, food safety regulations may require specific tests for microbial quality.

Farmers often use drip irrigation in high tunnels — more than 75 percent of the Indiana growers we surveyed used it. Hand-watering is also common (used by about 33 percent of surveyed growers), and sprinklers (about 20 percent).

It's not unusual to have more than one irrigation system. That said, the most effective irrigation system is one that's designed for your structure, planting arrangement, crops, soil type, and water supply.

For example, in a sandy soil, a tomato crop may need two drip lines per bed. In a clay soil, the same crop may only need one drip line.

For a spinach crop, you may use overhead sprinklers to get the soil to the desired moisture content before you seed, and then maintain soil moisture during emergence. During crop growth, you may continue to irrigate with the sprinklers, or switch to several lines of drip tape.

Those who supply professional irrigation equipment often can advise on design. Your state extension service may have staff with irrigation expertise.

Irrigation schedules (when to irrigate and how much water to put on) depend on the crop and its growth stage, weather, soil type, and irrigation system. Your goal is to provide adequate water for crop production and quality — you do not want to apply so much water that the soil remains saturated or that excessive nutrients leach below the rooting zone. You can often track tomato fruit disorders (such as blossom end rot and cracking or splitting) back to inadequate irrigation management.

Each operation will need to develop its own irrigation schedule. Just because another tomato grower runs drip irrigation twice a day for an hour each time, it doesn't mean that schedule is appropriate in your system.

If your irrigation schedule requires frequent irrigation for regular periods, automating the system (even partially) can save lots of time. For instance, we spoke with a tomato crop producer who runs drip irrigation three to four hours a day that turns on and off automatically. About 10 percent of surveyed growers use irrigation controllers that turn on and off. These controllers may be set for timed irrigation (that is, they start at a particular time of day and run for a specified time). While timing is probably most common, you can get controllers that turn on and off based on soil moisture or other environmental measurements.

Table 3 describes the pros and cons of common irrigation systems.

Table 3. *Pros and cons of select irrigation systems.*

Irrigation System					
Drip		*Sprinkler*		*Hand*	
Pros	**Cons**	**Pros**	**Cons**	**Pros**	**Cons**
Makes localized water application	Drip lines get in the way of tillage, cultivation	Easy to wet a large area (especially before or after seeding)	Wets leaves	Makes very localized water application	Is labor intensive
Doesn't wet leaves as much, which reduces disease pressure	Must spend time laying out and picking up drip lines	Parts last longer; depending on system, maybe not as many	May wet alleyways	Easy to tailor quantity	May provide less uniform application
Requires only low pressure		Easy to automate	May wet people	No special set-up needed	
Easy to apply soluble fertilizers		May not get in the way of tillage, cultivation	Uses water less efficiently if soil is covered with impermeable mulch		
Can be used under mulches					
Easy to automate					

***A.** A drip tape. **B.** A lay-flat header line with drip tape lines. **C.** A drip tape in a larger tunnel. **D.** A sprinkler irrigation system. **E.** A header for drip tape attached to a garden hose. **F.** An irrigation water storage tank with a gravity feed to drip irrigation lines. **G.** A storage tank for collecting water from a high tunnel roof.*

11. Summary

Overall, our research found that Indiana farmers have had a positive experience with integrating high tunnels into their farm operations. The most important opportunities growers reported are the higher quality and shelf life of their high tunnel crops, the price premium they can obtain for having crops earlier in the season, and the higher yield of their high tunnel crops.

Farmers also told us they valued the opportunity to earn an income in the fall and winter months, the ability to attract and keep employees by offering employment for more (or all) months of the year, and the opportunity to grow crops that complement their farm business and that they would not otherwise be able to offer. These crops include greens and root crops to complement fall crops or agritourism, early berry crops to extend the time they can sell berries at the farmers' market, or varieties of delicate flowers or other crops they would not otherwise be able to offer their customers.

While high tunnels present many opportunities for growers, they are also time-consuming and labor-intensive to manage. Successful high tunnel production requires advanced planning and monitoring, including well-conceived business planning and site preparation, plus continued attention and monitoring of soil health, weed problems, pest changes, and disease management. Ultimately, as one grower said: "you get out what you put into it," because the benefits you gain will partly depend on the time and attention you are able to give to your high tunnel crops.

In this guide, we have shared important points and questions that other growers wish they had known or considered before investing in their high tunnels. We thank them for sharing their experiences with us, and now with you. We hope this handbook has been helpful and wish you success with your high tunnel production!

12. Resources

There are lots of resources out there to help you with high tunnels. We encourage you to browse these suggestions and find the information suited to your unique goals and needs.

Purdue Extension

extension.purdue.edu

Find your county office at extension.purdue.edu/Pages/countyoffices.aspx or (888) EXT-INFO.

Books

Coleman, Eliot. *Four-Season Harvest: Organic Vegetables from Your Home Garden All Year Long*. Chelsea Green Publishing, 2012.

Coleman, Eliot. *The New Organic Grower: A Master's Manual of Tools and Techniques for the Home and Market Gardener*. Chelsea Green Publishing, 1995.

Fortier, Jean-Martin, and Marie Bilodeau. *The Market Gardener: A Successful Grower's Handbook for Small-scale Organic Farming*. New Society Publishers, 2014.

Hartman, Ben. The Lean Farm: How to Minimize Waste, Increase Efficiency, and Maximize Value and Profits with Less Work. Chelsea Green Publishing, 2015.

Mefferd, Andrew. *The Greenhouse and Hoophouse Grower's Handbook*. Chelsea Green Publishing, 2017.

Solomon, Steve and Erica Reinheimer. *The Intelligent Gardener; Growing Nutrient-dense Food*. New Society Publishers, 2012.

Stone, Curtis. *The Urban Farmer: Growing Food for Profit on Leased and Borrowed Land*. New Society Publishers, 2015.

General High Tunnel Websites

eXtension "Introduction to High Tunnels"
articles.extension.org/pages/18358/introduction-to-high-tunnels

HighTunnels.org
hightunnels.org

University of Kentucky High Tunnel Research Facility
ukhtrf.webs.com/production

Rutgers University: Sustainable Farming on the Urban Fringe website ("High Tunnels in New Jersey")
sustainable-farming.rutgers.edu/high-tunnels-in-new-jersey

USDA-Sustainable Agriculture Research and Education (SARE). Season Extension: "Types and Construction"
www.sare.org/Learning-Center/Topic-Rooms/High-Tunnels-and-Other-Season-Extension-Techniques/Season-Extension-Types-and-Construction

Handbooks

Bachmann, Janet. *Season Extension Techniques for Market Gardeners*, ATTRA 2005. attra.ncat.org/attra-pub/summaries/summary.php?pub=366.

Blomgren, Ted and Tracy Frisch. *High Tunnels: Using Low-Cost Technology to Increase Yields, Improve Quality and Extend the Season*. University of Vermont Center for Sustainable Agriculture, May 2007. www.sare.org/Learning-Center/SARE-Project-Products/Northeast-SARE-Project-Products/High-Tunnels.

Hannan, Joe, et al. *Iowa High Tunnel Fruit and Vegetable Production Manual*, Iowa State University Extension publication HORT 3060. store.extension.iastate.edu/product/13342.

Thompson, Collin. "Planning and Siting for Hoophouses." The North Farm, Michigan State University Extension. www.msunorthfarm.org/uploads/3/8/2/8/38288527/the_north_farm_planning_and_siting_for_hoophouses.compressed.pdf.

Thompson, Collin. "Keeping Your Hoophouse Busy." The North Farm, Michigan State University Extension. www.msunorthfarm.org/uploads/3/8/2/8/38288527/keeping_your_hoophouse_busy_-_miffs.compressed.pdf.

Jim French, Kimberly Oxley, Tom Buller, and Cary Rivard. 2018. Growing Under Cover: A Guide to Polytunnel Options for Kansas Growers. A Kansas Rural Center Publication. kansasruralcenter.org/growing-under-cover.

Select High Tunnel Suppliers

Atlas Greenhouse
www.atlasgreenhouse.com/

Farmtek
www.farmtek.com

Farmer's Friend, LLC
farmersfriendllc.com

Four Season Tools
www.smallfarmtools.com

Nifty Hoops
www.niftyhoops.com

Rimol Greenhouse Systems
www.rimolgreenhouses.com

Rough Brothers, Inc.
www.roughbros.com

Stuppy Greenhouse
www.stuppy.com

Zimmerman High Tunnels & Greenhouses
www.zimmermanshightunnels.com

How to Build High Tunnels

"How to Build High Tunnels" video from Utah State University Extension
www.youtube.com/watch?v=RytuhqGBxZA

"Resources" page from The North Farm, Michigan State University
www.msunorthfarm.org

"Rainwater Catchment from a High Tunnel for Irrigation Use" video from Iowa State Extension
www.youtube.com/watch?v=XsxRZQR_7VU

Planting Guides

"Winter Growing Guide" from Johnny's Selected Seeds
www.johnnyseeds.com/growers-library/vegetables/winter-growing-guide-high-tunnel-scheduling.html

Plant Disease and Insect Identification

Caldwell, Brian, Eric Sideman, Abby Seaman, Anthony Shelton, and Christine Smart. Resource Guide for Organic Insect and Disease Management. New York State Agricultural Experiment Station, Cornell University.
cvp.cce.cornell.edu/submission.php?id=37.

"Natural Enemy Field Guide" from Ohio State University Extension
u.osu.edu/pestmanagement/files/2017/02/Final-NE-Guide-for-GLVWG2022017-rpiftt.pdf

Egel, Dan, and Shubin Saha. *Vegetable Diseases: Tomato Disease Management in Greenhouses*. Purdue Extension publication BP-197-W.
edustore.purdue.edu/item.asp?Item_Number=BP-197-W.

Foster, Ricky E., and John L. Obermeyer. *Vegetable Insect Identification*. Purdue Extension publication E-65-W.
edustore.purdue.edu/item.asp?Item_Number=E-65-W.

Vegetable Management

Midwest Vegetable Production Guide for Commercial Growers
mwveguide.org

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August 2018

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Vegetable Crops Hotline
A newsletter for commercial vegetable growers prepared by the Purdue University Cooperative Extension Service

Setting Your Transplants Up for Success

APRIL 19, 2023 - INCLUDED IN ISSUE: 717

BY: PETRUS LANGENHOVEN **AND** LIZ MAYNARD

As we approach warmer days in May and June, it's time to prepare for transplanting warm-season vegetable crops such as tomatoes, peppers, eggplant, and squash. Growers preparing vegetable transplants should plan for the process of hardening or conditioning their transplants to outdoor temperatures, light, and soil moisture conditions. By now, you should have started your transplants indoors. Greenhouse growing conditions are very different from outdoor conditions. Reduced light transmission (because of the glazing material) and controlled climatic and soil moisture conditions indoors lead to transplants that are poorly adapted to harsher outdoor growing conditions. A gradual introduction to outdoor growing stresses will result in higher carbohydrate levels in the plant, prompt additional root development, and thicken plant cell walls. Firmer and harder transplants will result in a higher transplant-establishing rate. This article will discuss the process of transplant hardening/conditioning and best practices for transplant establishment.

Figure 1. Processing tomato seedlings delivered and ready for transplant (Photo by Liz Maynard).

Hardening or Conditioning of Transplants

Purpose

- The intention is to slow plant growth, not stop plant growth.
- To reduce transplant shock by slowing transplant growth.
- To build up carbohydrate and nutrient reserves in the seedling.
- To get the plant physiologically adapted to higher light and lower soil moisture levels.
- To lower the humidity.
- To adapt the plant to temperature swings and lower temperatures.

When is it needed?

- Needed for transplants destined for open field settings.
- Might not be needed for transplants planted in a high tunnel.
- Depends on where the transplants were grown.
    - Glass greenhouse-grown transplants need to be hardened.
    - Transplants grown in a heated poly greenhouse need to be hardened.
    - Transplants grown in an unheated high tunnel do not have to be hardened when transplanted into a high tunnel but will require some hardening for field setting.

Managing nutrients, irrigation, sunlight, and temperature

- Begin conditioning your transplants 4-8 days before setting the plants in the field.
- Move plants outdoors during the day to a shady spot when temperatures are at least 50°F (Figure 2).
- Progressively increase the amount of sunlight the plants receive.
- Move the transplants indoors at night if temperatures below 50°F are expected.
- Don't move tender plants outdoors when windy or temperatures are below 50°F.
- During the last 2-3 days of hardening, plants can be left outside permanently in direct sunlight.
- While adjusting plants to outdoor light conditions, reduce the amount or frequency of water plants receive. Do not let plants wilt.
- Do not over-fertilize seedlings during hardening.

Figure 2. Transplant hardening area covered with shade cloth and lattice on the side. Lattice and shade cloth can be removed towards end of hardening period. (Photo by Liz Maynard).

Practical examples of how to do it

- Keep in mind that this is a general guide. Adjust according to your local weather conditions and timeline budgeted for hardening. Manage the conditioning process by observing your plants regularly for signs of stress.
- Below is a process growers may follow if they decide to use a shade house with different shade levels. The shade house should also protect the plants against excessive wind.
    - Initially, place plants under 50% shade for 3 hours. You may choose to only use 20% shade.
    - Increase the light and total time spent outside by 1-2 hours per day.
    - On day 3, move the plants to 20% shade.
    - During this process, return plants to the greenhouse every day. To make this easier, place plants on a wagon or cart that can easily be moved to the greenhouse or shed during the night.
    - On day 6, move plants permanently outside in the full sun.
    - On day 8, transplants are ready to be planted.

- Cold frames are ideal for conditioning plants and might be a cheaper solution on a small scale than a shade house.
- If you do not have a shade house, move the plants into the shade of a tree. Gradually introduce more sunlight, as mentioned above. The shady spot under the tree might change during the day. Move the transplants so that direct sunlight does not fall on them during the first few days.
- While introducing the plants to more light and variable temperatures, gradually decrease the irrigation frequency and volume.
    - Monitor plants regularly. Don't allow plants to wilt.
    - Don't withhold water to the point of seedling stress.
    - Depending on your watering schedule, reduce the irrigation duration or frequency. When irrigating, wet all the substrate in the plug cell.
- Your seedlings are now conditioned and ready for transplanting.

Holding transplants

Purpose

When weather or other events don't permit transplanting at the desired growth stage, prevent plants from overgrowing yet keep them in good condition for transplanting.

Managing fertility, irrigation, and sunlight

Manage irrigation and fertility in the same way as during the conditioning process. However, be sure to monitor for nutrient stresses and add fertility as needed.

Holding area requirements

Preferably, hold transplants in a well-ventilated shade house.

Fertilizer at Planting Time, Starter Fertilizer

- Provide readily available nutrients close to seedling roots.
- Traditionally most important in cool soils low in P.
- In systems relying on organic N, some readily available N may be helpful in cool soil.
- Apply after conditioning when seedlings are still in flats, apply in transplant water, or apply in/near the transplant hole.

'Starter' fertilizer is applied at the time of transplanting so that nutrients will be available near the roots of young plants. This enables the plant to take up enough nutrients to establish quickly without requiring a lot of root growth to access nutrients spread through the soil profile. Typically, it represents a small amount of the total nitrogen and potassium required by the plant and a larger proportion of the phosphorus. This is because plants do not need as much phosphorus as nitrogen and potassium, phosphorus does not readily move towards roots, and root growth is slow in cool soils.

Crops are most responsive to starter fertilizer when the soil is cool and wet and soil nutrient levels are low. This is especially true for the response to phosphorus. If the soil is warm and soil tests indicate a high level of phosphorus, less benefit from phosphorus is likely. Under these conditions, a starter fertilizer with only nitrogen could be used. In

systems that rely on organic nitrogen, the cool soils of spring can lead to inadequate nitrogen availability because microbes responsible for releasing nitrogen from organic materials are not very active. Under these conditions, applying a starter organic fertilizer that contains some soluble nitrogen is likely to benefit the crop.

Starter fertilizers can be applied in several ways. One option is to fertigate seedlings while still in the flats shortly before transplanting. Another is to include fertilizer in the solution used to water in the transplants. A method appropriate for hand transplant systems is to mix solid fertilizer into the transplant hole at the time of transplanting. The table below provides examples of materials and amounts for use as starter fertilizers.

Material	Amount per 1 gal	Amount per 50 gal	Notes
Soluble fertilizer 9-45-15	1 tablespoon	2.5 lb.	Apply 8 fl. oz. per plant after transplanting
Liquid 10-34-0	1 tablespoon	2 pints	
Calcium nitrate 15.5-0-0		2.5 lb.	
Fish emulsion, 3-2-2	2 fl. oz.	6.25 pints	
Fish emulsion, 2-4-1	3 fl. oz.	10 pints	
	Amount per plant	**Amount per 100 plants**	
Blood meal 13-0-0	1 teaspoon	1 pint or 0.6 lb.	Mix well into soil in planting hole and water after planting
Alfalfa meal 3-1-3	2 to 4 tablespoons	6 to 12 pints or 1.5 to 3 lb.	

Table 1. Example materials and rates for starter fertilizer application to vegetable seedlings at the time of transplanting.

Best conditions for transplanting

- Minimum air temperature is 40°F for cool season and 50°F for warm season crops.
- Soil temperature is 50°F for cool season and 60°F for warm season crops.
- Humid, overcast, calm.
- Adequate soil moisture.
- Protection from strong winds and frost is available if needed (see **Protect Early Planted Warm Season Vegetables** in VCH Issue 672).

Transplants will establish best if air and soil temperatures are optimum for growth, the soil is moist, and it is overcast, humid, and not windy at the time of transplanting. Of course, it's not usually possible to wait for ideal conditions. Air temperature should at least be above the minimum for growth, which is about 40°F for cool season and 50°F for warm season crops. To minimize risk, plant frost-tender plants after the **likelihood of frost has passed (https://ag.purdue.edu/indiana-state-climate/wp-content/uploads/2019/09/Spring32_90.jpg)** if they won't be protected by row cover. If riskier early plantings are part of the plan, consider planning for frost protection as well. For more detailed frost/freeze records, refer to **A Look at the Freeze Date Tool from Midwestern Regional Climate Center (https://vegcropshotline.org//article/a-look-at-the-freeze-date-tool-from-midwestern-regional-climate-center/)** from VCH Issue 713.

Soil temperature is also important. For cool season crops, 50°F is desired, and for warm season 60°F. Use a soil thermometer to check, or make use of measurements from the **Indiana Mesonet (https://campbellcloud.io/stations.php)**. Hourly soil temperatures lag behind air temperature, so the minimum

occurs mid to late morning and the peak late afternoon to early evening each day.

Figure 3. Tall tomato transplants exposed to wind could be damaged (Photo by Liz Maynard).

The water you apply after transplanting will provide soil moisture, but existing moisture is also important to consider. If too moist, the soil structure is likely to be damaged during the planting process. If too dry and rain or irrigation does not come soon, root growth may be restricted.

Windy conditions cause seedlings to lose water more quickly, and without an established root system, they can easily become stressed (Figures 3, 4, and 5). Windblown sand can create tiny wounds in leaves that open the plant to disease. Windbreaks of snow fences, strips of cover crops left standing (that can be terminated later if desired), or other vegetation can help to protect seedlings.

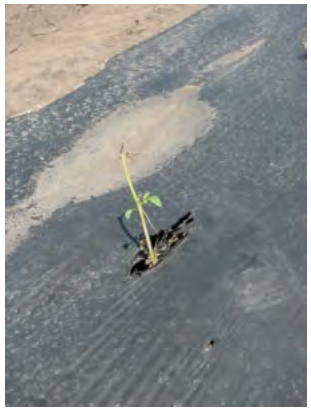

Figure 4. Wind damage on tomato seedling: leaves desiccated and main stem broken off, 2 weeks after transplanting (Photo by Liz Maynard).

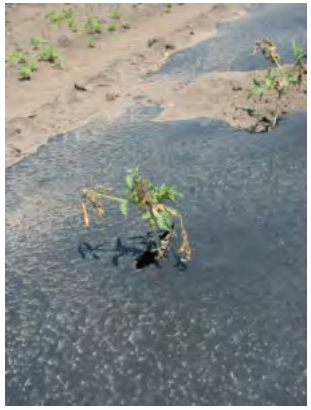

Figure 5. Tomato seedling with dead growing point and desiccated leaves from wind damage, 2 weeks after transplanting (Photo by Liz Maynard).

At the time of transplanting

- Equipment is available for many scales and types of systems.
- Water transplants thoroughly before taking them to the field and water trays in the field as needed.
- Handle seedlings with care.
- Set equipment for proper planting depth.
- Assure contact of the root ball with soil and good coverage of root ball and pot (if present).
- Water in thoroughly.

Transplanting equipment varies with farm type and scale. It may be a trowel or Hori Hori garden knife, hand-held plant setter, paperpot (Figure 8), waterwheel (Figure 6), or mechanical transplanter. Dibbles, single or rolling, don't actually transplant but create holes for setting by hand. Whatever the method, key points apply.

Figure 6. Waterwheel transplanter (Photo by Kelley Freeman).

Before taking seedlings to the field, water them thoroughly to saturate the growing media. Be prepared to water the trays again in the field if they dry out before they get transplanted.

It's best to handle the seedling by the root ball and/or leaves – not the stem. A stem pinched too hard will recover with difficulty, while a torn leaf will soon be replaced with another.

Adjusting the depth of planting for the size and type of seedling is important. For all crops, plant deep enough to fully cover the root ball, the growing medium, and if the seedling is in a fiber or paper pot, the top edges of the container. If growing medium or container edges are left uncovered, they will dry out and wick water away from the root zone. Tomatoes form roots readily along the stem and can be buried up to the first true leaf or, if lower leaves have fallen off, up to the first healthy true leaf. Peppers should be covered at least to the cotyledon and may be buried up to the first true leaf. Cucurbits can be buried up to, but not over, the cotyledons or seed leaves (Figure 7). Be careful not to plant too deep when using grafted plants – the graft union should be above ground.

Figure 7. Transplant set and watered in. Substrate covered with soil (Photo by Kelley Freeman).

Especially with mechanized planting, it is important to check that plants end up planted at the correct depth and are properly covered (Figure 9). In some situations, it is worth having someone walk behind the transplanter to double-check. That person can also set plants in spots that might have been missed.

Figure 8. Spinach being transplanted with a paper pot transplanter (Photo by Liz Maynard).

Figure 9. Spinach transplanted with a paperpot transplanter. Note how the edges of paperpot are visible above the soil surface: they should be covered so that they do not wick moisture away from roots. (Photo by Liz Maynard).

When planting into plastic mulch, ensure that the seedling stem does not constantly rub against the edge of the mulch hole. This can seriously damage the stem, especially with more tender seedlings. Windy conditions and/or high temperatures, combined with black plastic, increase the likelihood of injury to the plant stem from the plastic mulch.

Water in each plant with 8 fl. oz. of starter solution or plain water right after transplanting. Use more if it is hot, windy, and dry, and consider reducing the concentration of fertilizer in the starter solution.

Check plants in the days after transplanting. It may take a few days for them to start growing. Scout for pests that may be causing damage, such as cutworms. If some plants don't survive, try to figure out why. Replace them within a week to minimize crop delay. If dry conditions prevail, irrigation may be needed. Your observations and notes can be used to increase success in the future.

In summary, what are the best practices?

1. Harden off to reduce transplant shock.
2. Use a starter fertilizer just before or at transplanting.
3. Take weather and soil conditions into account when selecting the transplant date.
4. Water well before transplanting.
5. Handle seedlings carefully.
6. Plant at the correct depth: not too deep or too shallow.
7. Water in thoroughly.
8. Be prepared to protect the transplants from frost, strong wind, and windblown sand, if needed.
9. Check plants in a few days; note observations; replant within a week if needed.
10. Plan to manage plant stress during the first 1-2 weeks after transplanting.

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Cooperative Extension Service

Vegetable Production Guide for Commercial Growers, 2024-25

2024-25
Vegetable Production Guide for Commercial Growers

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This guide is for reference only: The most recent product label is the final authority concerning application rates, precautions, harvest intervals, and other relevant information.

Contact your county Cooperative Extension Service agent if you need assistance.

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Cover photo: Flower of cucurbit plant. Image by Kim Leonberger, University of Kentucky

Introduction

Fruit and Vegetable Production and Marketing

Successful vegetable production generally requires the grower to make daily decisions regarding pest management, irrigation, and cultural practices. Would-be growers unwilling to make serious investments of time (and money) should not attempt to expand beyond a space at the farmers' market. It is important for vegetable growers to have a market outlet for their product before they choose to start production. Good marketing plans start with the customer and work backward to production. Potential growers should first determine exactly what buyers want, how they want it, and when they want it. They then must determine how these crops should be grown. Even selecting varieties and determining planting times are basic marketing decisions. Kentucky growers should pay particular attention to comparisons of marketing time required, compatibility with off-farm employment, compatibility with tobacco production, and other farm demands. Individual situations vary, and producers often must learn about their particular markets by starting small and getting a foot in the door.

Marketing Options

Direct Marketing. Marketing directly to consumers includes sales at local farmers' markets, on-farm markets, roadside stands, farm festival markets, pick-your-own sites, or any combination of these methods. Direct marketing of vegetables has expanded considerably in Kentucky in recent years. Growers have gravitated to direct marketing because they have the flexibility to determine how much or little they wish to grow and, because they can often charge retail prices for their product, their per-acre revenue may be higher.

On-Farm or Roadside (Tailgate) Markets. These markets need not be elaborate but do need to be highly visible and located close to high-traffic areas for success. Direct marketing can also succeed in more remote locations but will require more advertising and promotion.

Many consumers in urban centers now consider visits to on-farm or farmers' markets recreational activities because people enjoy seeing farms and talking with farmers. Some growers have developed seasonal festival days and markets to satisfy this demand. Such "entertainment farming" and some other forms of direct marketing require liability insurance coverage, large time commitments, and employees with friendly, courteous attitudes.

Pick-Your-Own, or "U-Pick" Sales. This type of direct marketing appears to be declining nationally because consumers have less time and energy available for harvesting produce. U-picks eliminate some of the harvesting, transportation, and marketing costs for growers but may require additional management, supervision, and liability insurance coverage.

Local Town, County, or Community Farmers' Markets. The number of registered farmers' markets has continued to grow in Kentucky. According to the Kentucky Department of Agriculture, over 159 markets were operating in Kentucky in 2017, representing over 2,500 different vendors from 106 different counties. Markets located in larger metropolitan areas tend to generate greater overall sales as well as greater per-vendor sales. These markets are probably the easiest way for new growers to sell small volumes of produce. Less marketing time is required, and individual growers do not usually bear all advertising and promotion costs. Farmers should check with their local county agents to determine what rules and regulations each market may have. Those producers wanting to market a processed food product should also check with the Departments of Agriculture and Public Health about the regulations governing the sale of processed food. In addition, the Kentucky Department of Agriculture has printed a farmers' market manual. An electronic version of this manual can be found at: kyagr.com/marketing/farmmarket.

Vegetable marketing and production plans need to be developed simultaneously; the most successful growers put equal emphasis on growing and marketing their products.

Community Supported Agriculture (CSA). Though the concept of community supported agriculture (CSA) began in Europe as early as the 1960s, it is still relatively new to many regions of the United States. Basically, a CSA consists of "shareholders" who pay a set fee to a grower or group of growers for a weekly supply of fresh vegetables during the growing season. Because the members of a CSA pay for their "subscription" at the beginning of a growing season, they share some of the risk with the farmer. As part of their agreement with the grower, members acknowledge that a poor harvest due to unfavorable weather or pests means their shares may be smaller than usual. By direct sales to community members, growers receive better prices for their crops and can gain some financial security. Shareholders often have a greater sense of community involvement, knowing that they are helping support local agriculture.

Produce Auctions. Produce auctions have been popular for small growers in some parts of Kentucky.

Growers bring produce to the auction facility, where it is sold to the highest bidder. The auction company (sometimes a growers' organization) charges a flat commission of about 10 to 15 percent. Both large and small lots are accommodated at some auctions. At the large auctions, some of the bidders are operators of medium-to-large retail produce markets and stands.

Marketing Cooperatives. A marketing cooperative is just one form of indirect marketing in which the producer deals with an intermediary rather than the final consumer. Although most forms of indirect marketing require less time of individual growers, they usually demand more product uniformity, quality, and post-harvest care.

Grower-owned cooperatives or marketing associations are able to assemble truckloads of produce required by large customers, which would not be possible for small growers acting individually. Formally organized cooperatives also may provide technical assistance to growers and help secure seed, boxes, and other needed supplies. In some cases, specialized equipment is shared by growers.

Co-ops usually own and operate facilities with some combination of grading, packing, cooling, and storage equipment for their members. Members typically employ a manager to oversee the co-op's daily operations. There are several small growers' cooperatives with grading, packing, and cooling facilities in Kentucky. Co-ops can offer good marketing opportunities for new growers in counties near the co-op facilities. For long-term success it is advisable that rules requiring minimum standards for quality be set. Poor quality produce that is allowed into the co-op can depress profits for all those involved.

Local Wholesalers, Grocers, and Restaurants. Many potential buyers can be found among local wholesalers, grocery stores, and restaurants. Most metropolitan areas have produce wholesalers who can be dependable buyers of moderate volumes. Local grocery stores (and some chain stores) are sometimes willing to buy directly from growers through direct store deliveries (DSDs). DSDs often are possible with smaller grocery stores or chains but are discouraged by many larger chains.

Many restaurants buy from local or regional wholesalers. However, more and more of them (usually upscale establishments) are promoting locally grown and seasonal items on their menus, so individual growers may be able to sell to them. Like most other forms of produce marketing, restaurant sales are based on good relationships developed over time.

Regional Wholesalers, Chain Store Distribution Centers, and Brokers. Marketing to regional wholesalers or large chain-store distribution centers requires consistent quality, often significant volumes, and in some cases, year-round supplies. These buyers often have specific and demanding requirements for product uniformity, types of containers, cooling, transportation, and delivery of fresh produce. In some cases, especially when supplies are plentiful, produce quality must exceed USDA grading standards. Increasingly, grower-shippers also are being asked to supply produce to their supermarket chain buyers with price-lookup (PLU) stickers already applied.

Larger buyers look for quality and consistency. They need good incentives to interrupt year-round supplies from other parts of the country to buy more local produce. Some chain store buyers will pay a premium for top-quality local produce.

Some growers use brokers to market produce. The brokers negotiate either purchases on behalf of the buyer or produce sales on behalf of the seller. Unlike wholesalers, brokers do not take delivery nor assume ownership (title) of the produce. Brokers usually never see what they are quoting for sale or negotiating to buy. Brokers charge a percentage commission on all sales or a flat rate for each carton of produce sold.

Processors. Nationwide consumption and demand for most canned and frozen vegetable products have been flat or declining. Much consolidation of production and processing vegetables has occurred in recent years, with most of the industry now located in California and a handful of northern states. No traditional vegetable processing companies are left in Kentucky.

Several fresh-cut processors exist in the state and have indicated a desire to buy more products from within Kentucky. It is unlikely, however, that fresh-cut and other forms of processing will represent a significant market for Kentucky produce in the near future.

Getting Help

A number of organizations are working to create new marketing opportunities for Kentucky vegetable growers:

Cooperative Extension Service. Many county Extension agents know the production and marketing opportunities in their counties. They can provide vegetable production information and access to marketing and production specialists. In addition, county Extension offices can obtain information from produce industry directories such as The Red Book or The Blue Book. These publications list produce buyers by city and state and also include ratings for promptness of payment and other pertinent information.

Kentucky Vegetable Growers Association. This organization sponsors annual educational meetings (usually during the first week of January) that include special sessions on produce marketing. Ask your county Extension agent to put you on the mailing list for the annual meeting program and registration form. The KVGA website is kyvga.com.

Kentucky Department of Agriculture (KDA). The Kentucky Department of Agriculture Division for Value-Added Horticulture and Aquaculture maintains a directory of Kentucky vegetable growers,

The Kentucky Department of Agriculture Office of Agricultural Marketing and Product Promotion supplies this logo to qualified growers and marketers.

marketing cooperatives, and produce markets and is working to develop several new programs linking vegetable producers and buyers. The department also supplies the "Kentucky Proud" logo to qualified growers and marketers and administers the Kentucky organic certification program. See Appendix A for KDA website addresses.

Kentucky Farm Bureau. The Kentucky Farm Bureau's Certified Roadside/Farm Market Program can put your farm market on the map. Attractive brochures with your market location, featured products, and other details are made available at the state's welcome centers, at some state tourist attractions, and on the Internet. Contact your local Kentucky Farm Bureau office or see Appendix A for the website address.

The Internet. A wide variety of information on vegetable production and marketing is available on the Internet. Internet resources include Extension publications on how best to grow, harvest, cool, grade, and pack vegetable crops. Wholesale prices are also posted from markets around the country along with situation reports for certain crops. For some of the best websites for commercial vegetable growers, see Appendix A.

General Production Considerations

Variety Selection

Most of the varieties listed in this guide have been selected through extensive trialing at the University of Kentucky and on farms across the Commonwealth. The varieties have been selected because they have shown the ability to produce high yields while maintaining a uniform quality. Most of the varieties also have been selected based on having some level of disease resistance. Judicious selection of resistant varieties can help growers reduce pesticide costs and increase profits. However, for many farmers selling direct retail, the absolute highest yield may not be as important as a particular quality attribute such as flavor or color. Keep in mind that the recommendations that are listed are simply that—recommendations. This means that these varieties have proven themselves to have reliable performance, and should do well in most instances. However, the omission of a variety does not mean it is necessarily a bad variety, just that we may not have enough information to recommend it.

Plant Spacing

The plant spacings listed throughout this guide reflect the optimum growing conditions to produce maximum commercial yields of a given crop. However, many vegetable growers in Kentucky produce a wide variety of crops. Therefore, you may find yourself planting on a slightly different spacing than is recommended simply to make the crops you are growing fit better into your production system. The "Plant Populations" table (page 8) lists the plant populations required per acre for a given row and in-row spacing.

Drip Irrigation for Vegetable Crops

A good guideline for commercial vegetable production is "if you can't irrigate it, don't plant it." Droughts are not uncommon in Kentucky; the drought of 1999 was worse than severe droughts that occurred in 1988, 1954, and 1930. The high temperatures and dry conditions during the summer of 2012 meant the entire state was considered to be under "severe or extreme" drought conditions. No one should consider commercial vegetable production without 1) access to water for irrigation and 2) access to a good high-pressure sprayer for disease control (see the "Disease Management" section). Drip irrigation makes sense for many vegetable crops grown in Kentucky. It has become standard practice for growers wanting to participate in wholesale vegetable markets. High yields from drip irrigation help keep growers in business during years when produce supplies are plentiful and margins are lower than usual. Those able to increase yields with drip can often achieve good returns in spite of lower prices. Results from numerous on-farm demonstrations at the University of Kentucky and Kentucky State University have shown that yields are usually doubled (sometimes tripled) with drip compared to non-irrigated, rain-fed production.

Although drip is best used together with plastic mulch on crops such as tomatoes, peppers, melons, and squash, even bare-ground plantings can benefit from drip irrigation. Some Kentucky growers have rolled out drip tube on bare-ground plantings of cabbage, sweet corn, and pumpkins. This practice has often made the difference between having a crop and not having one.

Water Resources

Water savings with drip are substantial—roughly half as much water can do the same or better job than a sprinkler system. A constant water source is essential. Even with water-saving drip, there are cases of water supplies drying up or being cut off in a drought year. County water has been used successfully by a number of growers in the state; it has been profitable in nearly all cases where it has been used. Other growers use streams, lakes, springs, or farm ponds. Several growers have constructed large farm ponds specifically for drip irrigation on vegetables. The size of the pond is critical, because some vegetable crops use enormous volumes of water (see "Tomato Crop Water Usage" graphic).

Installation and Equipment Costs

Contrary to popular opinion, drip irrigation is a relatively cheap and easy technology. It does not require an engineering degree or years of experience to install and operate a typical small-farm system. Costs for reusable equipment and components, together with annual disposable supplies, are about $2,550 (see drip irrigation costs example) for a one-acre system, with an additional $400 per-acre expense for each additional acre for systems up to about 10 acres in size. The $400 per-acre annual costs are for disposable drip irrigation tube (often called drip "tape") and embossed black plastic mulch.

The costliest piece of farm equipment required is the plastic layer/bed shaper; this machine costs from approximately $1,200 for a flatbed layer to about $5,000 for a plastic layer plus bed shaper with hydraulic counter-sway. Plastic layers are now also for lower horsepower tractors. These smaller plastic layers require only 35 hp to be pulled and do a fine job. Most growers who are farming a limited acreage have found these bed shapers/layers to be a better choice than traditional bed shapers. The waterwheel setter that is commonly used for transplanting through plastic mulch costs about $1,900-$2,300. Mulch layers that also form raised beds will require considerably more tractor horsepower. Raised beds may not be necessary on well-drained ground where standing water does not occur.

To help introduce the technology and reduce costs, many counties

have bought machinery to rent or loan to local farmers. In addition, UK Horticulture Department Extension associates and county Extension offices often conduct annual on-farm demonstrations that help new growers install small farm drip systems.

Setting up a small, low-pressure drip system involves more plumbing than engineering. Although most growers will need some experienced help with the initial layout and design specifications (pump sizes, filter, delivery line size, field zoning, etc.), actual installation and maintenance are very easy.

System Components

A small drip system consists of:

- Water source
- Pump at the water source
- Check valve and/or backflow prevention valve[1] (for city water)
- Fertilizer injector
- Filter
- Pressure regulator and gauge
- Intake and delivery lines
- Drip tubes (drip tape)

[1]Growers using city water are required by law to install a more sophisticated backflow prevention device rather than a simple check valve. Most of the items listed are available from dealers in Kentucky. See your county Extension agent for a list of irrigation dealers in the state.

Fertigation

Fertigation is the application of water-soluble fertilizer through the drip system using an injector that feeds the solution into the drip lines. Our fertigation recommendations are relatively simple and are found under the individual crops in this publication. We recommend not fertigating phosphorus on medium-textured soils in Kentucky. All the soil test-recommended potassium should be applied prior to planting on some soils, but additional potassium applied through the fertigation system may help reduce ripening disorders in tomatoes (see the "Fruiting Vegetable" chapter for details). Phosphorus and potassium should be broadcast with rates determined by soil test results prior to laying plastic.

Although all of the crop's nitrogen (N) requirement can be applied prior to laying plastic, most growers prefer to split N applications between a preplant dose and sidedressings applied at intervals through the drip system. Apply about half to two-thirds the N requirement preplant and dividing the remaining amount into weekly fertigations. Most growers use calcium or potassium nitrate, usually dissolved in water prior to fertigating. Although many fertilizers are easily soluble together, care must be taken not to mix fertilizers that may precipitate when together. This can lead to emitters clogging, resulting in inadequate irrigation. Often, high-phosphorous fertilizers can precipitate when mixed with sufficient concentrations of calcium.

PLANT POPULATIONS PER ACRE FOR A GIVEN ROW AND IN-ROW SPACING[1]

Row-spacing: center to center (inches)	In-row spacing (inches)[2]									
	6	9	12	15	18	24	30	36	42	48
30	34,848	23,232	17,424	13,939	11,616	8,712	6,970	5,808	4,978	4,356
36	29,040	19,360	14,520	11,616	9,680	7,260	5,808	4,840	4,149	3,630
42	24,891	16,594	12,446	9,956	8,297	6,223	4,978	4,149	3,556	3,111
48	21,780	14,520	10,890	8,712	7,260	5,445	4,356	3,630	3,111	2,723
54	19,360	12,907	9,680	7,744	6,453	4,840	3,872	3,227	2,766	2,420
60	17,424	11,616	8,712	6,970	5,808	4,356	3,485	2,904	2,489	2,178
66	15,840	10,560	7,920	6,336	5,280	3,960	3,168	2,640	2,263	1,980
72	14,510	9,673	7,255	5,804	4,837	3,628	2,902	2,418	2,073	1,814
78	13,403	8,935	6,702	5,361	4,468	3,351	2,681	2,234	1,915	1,675
84	12,437	8,291	6,219	4,975	4,146	3,109	2,487	2,073	1,777	1,555
90	11,616	7,744	5,808	4,646	3,872	2,904	2,323	1,936	1,659	1,452
96	10,890	7,260	5,445	4,356	3,630	2,723	2,178	1,815	1,556	1,361

[1] Assuming an entire acre is planted, drive rows are not accounted for.
[2] Assumes a single row

DRIP IRRIGATION COSTS: *(for up to 5-acre system)*

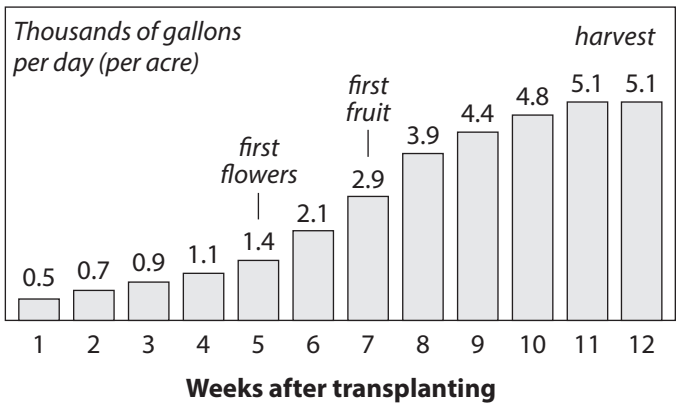
Item	***Cost (2015)***
2 in. centrifugal pump w/163cc engine	*$700*
Filter, sand (100 gpm)*	*725*
Single filter backflush valve	*260*
Fertilizer Injector	*200*
Layflat, 2" (300 ft. roll)	*105*
Suction hose and strainer	*95*
Fittings, valves, gauges, etc.	*100*
Total (5-7 yrs. reusable)	***$2,185***

Annual per-acre expenses

- *8-10 mil drip tape and black plastic mulch (1 mil, 4 ft wide): $0.05/ft x 7,260 linear ft ~ $400*
- *depreciation/rental costs on mulch layer and waterwheel setter*

**If using 2 sand filters a dual flush manifold adds $170 over a single flush manifold.*

TOMATO CROP WATER USAGE



Insect Management

Proper early identification of insect problems is essential in achieving satisfactory control. The following guidelines should aid in avoiding economic damage to vegetable crops from insect pests.

Although insecticides are important tools, successful management of insect and mite pests relies primarily on cultural practices. Proper cultural practices can minimize the chance for initiation and buildup of infestations. Early detection and diagnosis are key to pest management, as are the proper choice and proper application of pesticides when they are required. Vegetable producers should recognize and understand which pests have caused problems on their farms in the past and use nonchemical, preventive methods to help manage these pests when possible. Producers should regularly monitor insect and mite pests known to be problems in their areas and on the crops they are growing. Integrated pest management (IPM) guidelines for several commercial vegetable crops (cabbage, sweet corn, peppers, pumpkins) have been published by the University of Kentucky and are available through your county Extension office or on the Internet (see Appendix A).

Use crop rotation as a means of controlling certain insects such as corn rootworms in sweet corn. Grow varieties that are resistant to insects and disease when possible. Destroy or plow under crop residues immediately after the crop is harvested to reduce overwintering pest populations. Stimulate plant growth by proper irrigation and fertilization. Control weeds in and around crop fields. Weeds can be attractive to pest insects and may serve as hosts to insect-vectored diseases.

The following suggestions primarily are preventive methods rather than controls, and most should be carried out far in advance of the insect's appearance:

- Always properly identify and evaluate your insect problem.
- Learn to identify and conserve beneficial and harmless insects.
- Scout your fields on a regular basis to monitor insect activity and possible damage.
- Use IPM guidelines and treatment thresholds—available for most vegetable crops—to help you determine what level of damage can be tolerated before economic losses occur and treatment is required.
- If an insecticide is needed, select one that best fits your situation.
- Select an insecticide that is labeled for a wide variety of crops; this will minimize the chance of accidentally treating a crop that should not be treated with that insecticide and will reduce the number of products that must be purchased and stored.
- If possible, buy pesticides in quantities small enough to use up during the growing season.
- Select insecticides that do not require a long waiting period from application to harvest so you are not hampered in harvesting when the crop is ready.

Insecticides used to control vegetable insect pests come in several different forms. Dusts, baits, and granules are dry forms used as purchased. Baits are formulated with a pest attractant; dusts and granules include an inert carrier. Dry flowables (DF), emulsifiable concentrates (EC), flowables (F), liquids (L), soluble powders (SP), suspension concentrates (SC), water-dispersable granules (WDG), and wettable powders (WP) are formulations of insecticides that disperse when mixed in water. The latter are all used as sprays. For best results when applying dusts and sprays, thoroughly cover surfaces of infested plants.

Greenhouse Insect and Mite Management

The warm, humid conditions and abundant food in the greenhouse are ideal for pest buildup. Problems can be chronic unless recognized and corrected. Many insecticides used on vegetables in the field are prohibited in the greenhouse (see the "Relative Efficacy of Insecticides" table on the inside back cover).

Cultural Controls

Pests may enter the greenhouse in the summer when the ventilators are open. Others may be brought into the greenhouse on new plant material or in soil. Many are able to survive short periods of time between harvest or plant removal and production of the next crop. Cultural controls are the primary defense against infestation.

The following are proper cultural practices that will help prevent pest infestations:

- Maintain a clean, closely mowed area around the greenhouse to reduce pests that develop in rank growth.
- Remove all plants or any plant debris, and clean the greenhouse thoroughly after each production cycle.
- Keep doors, screens, and ventilators in good repair; use insect-proof netting when possible. (The extremely fine netting for thrip exclusion has been shown to limit air movement and may negatively impact disease management.)
- Use clean or sterile soils or ground media, tools, flats, and other equipment.
- Inspect new plants thoroughly to prevent introduction of insect or disease-infested material into the greenhouse.
- Watch for leaks or pooled water that can lead to fungus gnat infestations.
- If possible, allow the greenhouse to freeze in winter to eliminate tender insects such as whiteflies.
- Avoid wearing yellow clothing, which is attractive to many insect pests.
- Eliminate infestations by discarding or removing heavily infested material.

Monitoring

Early detection and diagnosis of pest infestations will allow you to make pest control decisions before the problem gets out of hand. It is good practice, therefore, to make weekly inspections of plants in all sections of the greenhouse.

Insect monitoring devices are also available. Yellow sticky cards (PT Insect Monitoring Cards, or Gempler's—gemplers.com) are highly attractive to winged aphids, leafminer adults, whiteflies, leafhoppers, thrips (blue cards can also be used with thrips), various flies, and other insects. These cards can be used to alert you to the presence of a pest and identify hot spots in the greenhouse. One to three cards per 1,000 square feet in the greenhouse is recommended; the cards should be changed weekly. If you cannot identify a trapped insect, contact your county Extension agent for assistance. Mass trapping products such as sticky tapes also are available for thrips, whitefly, leafminer, and fungus gnat detection and management.

Protecting Honey Bees from Pesticides

Many valuable crops cannot be economically produced unless adequate numbers of honey bees are present to pollinate them. In addition, honey bees produce more than $50 million in honey and beeswax annually. Many pesticides are extremely hazardous to honey bees, but damage can be minimized if the pesticide user and the beekeeper cooperate and each takes the proper precautions.

Crops Pollinated by Honey Bees

Some of the crops that require bee pollination are cucumber, squash, pumpkin, watermelon, and muskmelon. Honey bee colonies can be rented in many areas. One or two good hives of bees per acre is suggested to ensure a good yield of high quality fruit, particularly now that parasitic mites are killing many of the wild honey bees.

The Pesticide User's Role

- Be familiar with the Kentucky Pollinator Protection plan (https://www.kyagr.com/statevet/documents/OSV_Bee_KY-Pollinator-Pro-Plan.pdf).
- Know if and where managed honey bee colonies are located near your fields and how to contact these beekeepers.
- Use pesticides only when needed and only at the rates recommended on the label.
- If possible, select one of the least hazardous pesticides to pollinators, especially for use on flowering plants that attract bees. Pesticides with the honey bee inside the red diamond icon require notification of nearby beekeepers if applied to crops or weeds in bloom (see labels for specific instructions). An online communication tool is available to notify beekeepers anonymously within 5 miles 48 hours prior to the application (https://www.kyagr-apps.com/Pollinator/).
- Do not apply pesticides when honey bees are active in the field. Applications late in the afternoon (after 6:00 pm) or at night are least likely to damage bees.
- Do not apply pesticides when plants are in flower unless absolutely necessary.
- Avoid pesticide drift into apiaries or areas where crops or wild plants are flowering. Plant crops requiring heavy pesticide applications in areas as far from managed honey bee colonies as possible.
- Notify nearby beekeepers several days before you apply a pesticide as indicated by the labeling.

The Beekeeper's Role

- Be familiar with the Kentucky Pollinator Protection plan (https://www.kyagr.com/statevet/documents/OSV_Bee_KY-Pollinator-Pro-Plan.pdf).
- Locate colonies away from areas of heavy pesticide use when practical.
- Post your name, address, and phone number conspicuously at your apiary, and tell neighboring farmers where your colonies are located.
- Know what pesticides are commonly used in your area, and be prepared to confine or remove your bees if notified that a pesticide will be applied. Commonly used pesticides, grouped according to hazard, are listed, right. A plastic sheet can be used at night or in the early morning to confine bees and protect them from short-residual pesticides. However, heat builds up rapidly once the plastic is exposed to the sun, and it must be removed. Wet burlap can be used for periods of a day or more. This may be impractical for large numbers of hives.
- Relocate colonies that are in danger of repeated contact with pesticides in Group 1 in the table "Commonly Used Pesticides," right.
- Register your hive locations with the Kentucky Department of Agriculture to receive timely pesticide application notifications near your colonies (https://www.kyagr-apps.com/Pollinator/).
- Be prepared to temporarily move or close colonies if warned of a risky pesticide application in your area.

BIOLOGICAL PRODUCTS FOR INSECT CONTROL IN GREENHOUSES

Biocontrol Agent	Insects and Mites to be Controlled	Comments
Encarsia formosa	Greenhouse whitefly	Minute wasp that is a parasitoid of whiteflies immatures (3rd and 4th instars). Not effective against silverleaf whiteflies.
Eretmocerus eremicus, Eretmocerus mundus	Silverleaf whitefly	Minute wasp that is a parasitoid of whiteflies immatures (3rd and 4th instars). Will also attack greenhouse whitefly.
Delphastus catalinae	Whiteflies, both greenhouse and silverleaf	A tiny predatory beetle that feeds on the eggs and nymphs.
Verticillium lecanii	Whiteflies, thrips, and spider mites	A white entopathogenic fungus that attacks insects, killing them in 7 to 10 days. More effective on whiteflies than the other pests.
Amblyseius swirskii, Hypoaspis miles, Neoseiulus cucumeris	Immature thrips and whiteflies	Small predatory mites that hunt for insect prey. Often found under leaves near the main vein.
Mesoseiulus longipes, Neoseiulus californicus, Phytoseiulus persimilis, Galendromus occidentalis	Spider mites	Small predatory mites that hunt for spider mites. Will feed on pollen in the absence of prey.
Minute pirate bugs: *Orius insidiosus, Orius laevigatus, Orius strigicollis*	Thrips, and to a less extent aphids, and other insect eggs.	Tiny predatory bugs that can be used against thrips.
Green lacewings: *Chrysoperla carnea*	Aphids, but will also feed on thrips, whiteflies, and moth eggs.	Both the larvae are predatory on these greenhouse pests. Sold as eggs or larvae.
Lady beetles: *Adalia bipunctata, Hippodamia convergens*	Various species of aphids	
Aphidius colemani, Aphidius ervi, Aphidius matricariae, Aphelinus abdominalis	Various species of aphids	These minute wasps are parasitoids of aphids. Aphids will form mummies when attacked. Different species have a preference to different aphid hosts.
Aphidoletes aphidimyza	Various species of aphids	A predatory midge that feeds on aphids.

INSECTICIDES EXPRESSLY LABELLED FOR GREENHOUSE-GROWN VEGETABLES

Product	IRAC Code	Crops	Target Pests	Comments
Admire 4.6 F	4A	Cucurbits, fruiting vegetables	Aphids, whiteflies	Planthouse use for transplant production
Admire 4.6 F	4A	Cucumbers	Aphids, whiteflies	Drench applications for plants in soil only
Agri-Mek 0.7 SC	6	Tomatoes	Spider mites, russet mite, thrips, leafminers	Not for use on plants grown for transplants
Akari 5 SC	21A	Cucumbers, tomatoes, peppers	Various mites, psyllid, whiteflies	
Altus 1.67 SL	4D	Cucumbers, lettuce, tomatoes, peppers	Aphids, leafhoppers, squash bug, whiteflies, Colorado potato beetle, psyllids	Foliar or drench applications
Altus 1.67 SL	4D	Brassica leafy vegetables, cucurbit vegetables, fruiting vegetables, leafy vegetables, legume vegetables, root vegetables, turnip greens	Aphids, leafhoppers, squash bug, whiteflies, Colorado potato beetle, psyllids	For transplant production only. Foliar or drench applications
Beleaf 50 SG	29	Tomatoes, cucumber, peppers	Aphids, plant bugs, whiteflies, psyllids, thrips	
Distance 0.86 EC	7C	Fruiting vegetables	Aphids, whiteflies, fungus gnats, shore flies	Do not apply to tomato varieties with fruit less than 1 inch in diameter or non-bell peppers
Exirel 0.83 SE	28	Cucumber, eggplant, pepper, tomato	Loopers, armyworms, aphds, whiteflies	Not for transplant production
Floramite SC	20B	Tomatoes	Two-spotted spider mite, broad mite	Not for transplant production
Kanemite 15 SC	20B	Fruiting vegetables, cucurbit vegetables	Two-spotted spider mite, broad mite	Not for transplant production
Pylon 2 L	13	Fruiting vegetables	Beet armyworm, southern armyworm, fall armyworm, yellow-striped armyworm, tomato pinworm, tomato fruitworm, hornworms, two-spotted spider mite, broad mite, thrips	Only for greenhouse use
Quasar 8.5 SL	4A	Tomatoes	Aphids, whiteflies, thrips, psyllids	
Rimon 0.83 EC	15	Tomato, cucumbers	Armyworms, Colorado potato beetle, European corn borer, leafminers, tomato fruitworm, tomato pinworm, thrips, whiteflies, stink bugs, pepper weevil	
TriStar 8.5 SL	4A	Peppers	Aphids, whiteflies, thrips, psyllids	
Quasar 8.5 SL TriStar 8.5 SL	4A	Transplants of leafy greens, leaf petiole vegetables, fruiting vegetables, brassica head and stem vegetables, kohlrabi, celtuce, Florence fennel, cucurbit vegetables, onions and other bulb vegetables	Aphids, whiteflies, thrips, leaf eating beetles, fungus gnat larvae, plant bugs, caterpillars, leafhoppers, mealybugs	

INSECTICIDE RESISTANCE ACTION COMMITTEE (IRAC) GROUPINGS

These insecticide groupings now appear on many labels. The groupings are based on mode of action of the insecticides. The codes allow users to determine if different insecticides share the same mode of action. This information should be used by growers to prevent/delay the development of resistance by not overusing products with the same mode of action.

Insecticide	Grouping
Acramite	20D
Actara	4A
Admire	4A
Agri-Mek	6
Altus	4D
Asana XL	3A
Assail	4A
Avaunt	22
Aztec	1B, 3A
Baythroid	3A
Belay	4A
Beleaf	29
Blackhawk	5
Brigade	3A
Bt kurstaki	11A
Coragen	28
Counter	1B
Courier	16
Danitol	3A
Diazinon	1B
Dibrom	1B
Dimethoate	1B

Insecticide	Grouping
Dimilin	15
Exirel	28
Force	3A
Fulfill	9B
Harvanta	28
Hero	3A
Intrepid	18
Kanemite	20B
Knack	7C
Lannate	1A
Magister	21A
Malathion	1B
Miteus	21A
Mocap	1B
Movento	23
Mustang Maxx	3A
Nealta	25
Nurizma	30
Oberon	23
Platinum	4A
Portal	21A
Pounce	3A

Insecticide	Grouping
PQZ	9B
Proaxis	3A
Proclaim	6
Pylon	13
Radiant	5
Rimon	15
Scorpion	4A
Sefina	9D
Sevin	1A
Sivanto	4D
Thimet	1B
Torac	21A
Transform	4C
Trident	11A
Trigard	17
Venom	4A
Verimark	28
Versys	9D
Vydate	1A
Warrior	3A
Zeal	10B

COMMONLY USED PESTICIDES AND THEIR RELATIVE HAZARDS TO HONEY BEES[1]

Group 1. Hazardous
abamectin (Agri-Mek)
acephate (Orthene)
bifenthrin (Brigade, Capture)
carbaryl (Sevin)
clothianidin (Belay)
cyantraniliprole (Exirel, Verimark)
cyfluthrin (Baythroid XL)
deltamethrin (Decis)
diazinon
dimethoate (Cygon)
dinotefuran (Scorpion, Venom)
emamectin benzoate (Proclaim)
esfenvalerate (Asana XL)
fenazaquin (Magister)
fenropathrin (Danitol)
gamma-cyhalothrin (Proaxis)
imidacloprid (Admire, Macho, Nuprid)
indoxacarb (Avaunt eVo)
lambda-cyhalothrin (Warrior)
malathion
methomyl (Lannate)
naled (Dibrom)
permethrin (Ambush, Pounce)
phosmet (Imidan)
thiamethoxam (Platinum, Actara)
tolfenpyrad (Torac)
zeta-cypermethrin (Mustang Maxx)

Group 2. Moderately Hazardous
disulfoton (Di-Syston)
DSMA
MSMA
oxamyl (Vydate)
paraquat (Gramoxone)
phorate (Thimet)
pyriproxifen (Esteem, Knack)
spinosad (Entrust, Tracer)
spinetoram (Radiant)

Group 3. Relatively Nonhazardous
azadirachtin (Align, Neem)
Bacillus thuringiensis
Bordeaux mixture
bromoxynil
cyromazine (Trigard)
captan
copper oxychloride sulfate
copper 8-quinlinolate
copper sulfate (Monohydrated)
dazomet (Basamid)
dicamba (Banvel D)
diflubenzuron (Dimilin)
dinocap (Karathane)
diquat
dodine (Cyprex)
endothall
EPTC (Eptam)
kaolin (Surround)
mancozeb
MCPA
nicotine sulfate
pyrethrins
simazine (Princep)
sulfur
thiram
Zineb
Ziram
2,4-D
2,4-DB

1 Adapted from E-53, "Protecting Honey Bees from Pesticides," G. Hunt, R. Edwards, R. Foster, Purdue University Cooperative Extension Service

Weed Management

The use of herbicides suggested in this publication is based on research at the University of Kentucky and elsewhere in the region. We have compiled lists of effective herbicides with their rates and times of application, along with selected information on the use and precautions of select pesticides. It is not possible to include every comment and suggestion in the limited space allowed in this publication. Growers are encouraged to obtain a copy of the label and read it carefully. Copies of most labels can be found at http://www.cdms.net/Label-Database. Most herbicides are now manufactured under different trade names by different companies. Only one representative trade name is presented in this publication for each active ingredient. Growers should compare costs of different brands that have the same active ingredient. Pesticide labels may change after the printing of this publication, so growers must always consult the label for the final word on crops covered, precautions, rates, and application methods. **The label is the law!**

Carefully follow the precautions stated on the container label. The use of herbicides for purposes other than those specified on the approved label is a violation of federal law. Such applications can be hazardous to people, the environment, and to crops. Use herbicides only on crops for which they are approved and recommended on the label. Use only recommended amounts. **Using too much material is a violation of the law!** It may damage the crop, make it unsafe for consumption, and wastes money. The EPA is authorized to seize any raw agricultural commodity moving in interstate commerce that has a pesticide residue in excess of the established tolerance. Residues of unlabeled chemicals detected on fresh produce can be traced back to your farm.

Apply herbicides only at times specified on the label for the growth stage of the crop and the weed. Observe the recommended intervals between the time of treatment and re-entry times and pre-harvest intervals. Guard against possible drift injury to nearby susceptible crops by spraying at lower pressures, using drift-reduction nozzles, and checking weather conditions prior to spraying. The use of herbicides should supplement other good weed-management practices.

Types of Herbicide Formulations

Herbicides may be formulated as solutions (L), emulsifiable concentrates (EC), microencapsulated (ME), wettable powders (WP), flowables (F), wettable dispersible granules (WDG), and granules (G), to name a few. Many herbicides are added to water and applied as solutions. Many spray mixtures require constant agitation to prevent the herbicides from settling to the bottom of the tank. Granular herbicides are applied dry. Do not mix different granular pesticides or mix them with fertilizers. Some herbicides are labeled for application through an irrigation system, others as fertilizer mixtures.

Method and Time of Treatment

Herbicides are applied in the following ways:

- **Preplant incorporated (PPI):** incorporated into the soil prior to planting the crop
- **Pre-emergence (PRE):** on the soil after planting but before weeds emerge
- **Post-transplant:** on the soil after crop is transplanted either before weeds emerge or after clean cultivation
- **Post-emergence (POST):** on weeds after weeds have emerged
- **Directed post-emergence:** as a directed or shielded post-emergence on small weeds in rows of taller crops or in row middles.

Follow specified amounts and pressures on the label in order to achieve complete coverage.

Tank Mixtures

For broad-spectrum weed control, more than one herbicide may be necessary. It is quite common to tank-mix two or more pre-emergent herbicides to obtain adequate weed control in vegetable crops. Due to space limitations, only a fraction of the allowable tank mixes are listed. Look on the label for a complete list.

Crop Rotation

Because soil residual activity varies considerably among different herbicides, follow the directions closely for crop rotation on the labels of all products used. See the "Herbicide Label Restrictions" table on page 16 for restrictions on planting vegetables after using specific herbicides.

Herbicide Sprayers

Even distribution of herbicides at the proper rate is essential to good weed control. A small variation in the rate of application of some herbicides may result in failure to control weeds, or it may cause crop injury. For spray applications of herbicides, a low-pressure sprayer that accurately sprays between 15 to 30 pounds per square inch is the most suitable for either broadcast or band spraying. Hand sprayers of 3- or 4-gallon capacity are suitable for small areas or for spot spraying. Tractor-mounted sprayers, pump-driven from the power takeoff, are quite satisfactory for field spraying.

A good herbicide sprayer should:

- Have a pump that is easily replaced, be resistant to wear and chemical oxidation, and have a capacity of 8 to 15 gallons per minute.
- Have a boom equipped with nozzles with replaceable tips. Nozzle spacing will depend on many factors, such as your crop and your equipment. For broadcast spraying, many manufacturers recommend 16- to 20-inch spacing between nozzles on the boom.
- Have mesh screens for the suction line and nozzles and a gauge that measures pressure accurately from

0 to 100 pounds per square inch. Mesh screen size may vary with the herbicide used. For most herbicides, a 50-mesh size is quite adequate.

- Have a mechanical or jet agitator to keep the spray solution well mixed and prevent the herbicide from settling to the bottom of the tank.

Hand Sprayers

To spray herbicides on small areas, the most reliable method of application is the 1- to 3-gallons compressed-air sprayer. These sprayers are simple to operate but require careful calibration to assure even distribution of the herbicide over the sprayed area. A general rule is to use 1 gallon of the herbicide mixture for every 400 square feet of soil surface. This volume should be sprayed evenly over the 400 square feet. Do not guess distances or areas to be sprayed. If you have not used a hand sprayer previously, it is a good idea to practice using the sprayer with water the first time. Accurately measure the amount of herbicide that is to be added to the sprayer. See Appendix C for converting rates per acre to rates for small areas.

Cleaning Sprayers

Clean herbicide sprayers thoroughly after each use especially for sulfonylureas (Group 2), growth regulator type herbicides, and oil-based herbicides. For many products, the screens and filters should also be taken apart and cleaned. Triazine product residues, for example, can adhere to screens and will injure non-target, sensitive crops. Flushing tanks, lines, booms, and nozzles with water is usually sufficient for sprayers used only with pre-emergence herbicides. For most other herbicides, the sprayer should first be rinsed with water, then cleaned with one of the following in 50 gallons of water:

- A half-gallon of household ammonia (let stand in sprayer overnight)
- 4 pounds trisodium phosphate cleaner
- 2 ½ pounds sal soda (washing soda/sodium carbonate)
- 2 pounds activated charcoal (leave in sprayer and lines 10 minutes)

NOTE: To remove traces of oil-based herbicides such as ester formulations of 2,4-D, rinse the sprayer with kerosene before rinsing it with water and the cleaners listed above. For specific cleaning directions, refer to the label.

Do not use herbicide sprayers to apply other pesticides on vegetable crops. In addition to the potential hazard to the crop from traces of herbicides left in the system, pressures used in herbicide sprayers are inadequate for spraying insecticides and fungicides. When an enterprise requires two herbicide sprayers, use only growth regulator type herbicides (e.g. 2,4-D) in one sprayer and use the other for other herbicides.

Dual Magnum 24(c) Label

Syngenta has agreed to provide a special local need label for the use of Dual Magnum in a wide selection of crops. Crops of specific interest to growers include cucumber, watermelon, transplanted cabbage, transplanted pepper, and okra among others. See the label for a full list. Growers must have a copy of the label in their possession when applying Dual Magnum to these crops. In addition, the use of Dual Magnum on crops listed in the special local need label may result in crop injury, crop yield reduction and/or crop loss. The decision to use this product in the manner described in the supplemental labeling must be made by each individual user on the basis of (i) anticipated benefits versus the potential risk, (ii) the severity of the target pest infestation, (iii) the cost and availability of alternative pest controls, and (iv) any other relevant factors.

RELATIVE RESPONSE OF WEEDS TO HERBICIDES*

	Cocklebur	Crabgrass	Fall Panicum	Foxtail	Galinsoga	Jimsonweed	Johnsongrass (seedlings)	Lambsquarters	Morningglory	Nutsedge, Yellow	Pigweed	Purslane	Ragweed, Common	Ragweed, Giant	Smartweed	Velvetleaf	Black Nightshade
Preplant Incorporated																	
Command	P	G	G	G	G	P	F	G	P	N	P	E	G	P	G	G	P
Devrinol	N	G	G	G	P	N	F	F	N	P	F	G	F	N	N	P	P
Eptam	P	G	G	G	F	N	G	P	N	G	F	P	P	P	P	P	N
Prefar	P	G	G	G	P	P	P	G	P	N	G	P	P	P	N	F	P
Treflan	N	G	G	G	P	N	G	F	N	N	G	F	P	N	N	N	N
Pre-emergence																	
Atrazine	G	P	P	F	G	G	N	G	G	P	G	G	G	G	G	G	G
Curbit	N	G	G	G	P	N	G	G	N	N	G	G	N	N	N	N	N
Dual	N	G	G	G	G	N	F	F	N	G	G	G	P	P	F	N	G
Goal	N	F	F	F	G	F	N	F	N	N	G	G	G	G	G	G	G
Micro-Tech	N	G	G	G	G	N	F	F	N	G	G	G	P	P	F	N	G
Sandea	G	N	N	N	P	P	N	F	F	G	G	N	G	G	G	G	N
Sencor	F	P	P	P	G	G	P	G	F	N	G	G	G	F	G	F	P
Lorox	F	F	F	F	G	F	P	G	F	N	G	G	G	F	F	F	P
Prowl	N	G	G	G	F	N	F	F	N	N	G	F	P	P	F	F	P
Post-emergence																	
Basagran	G	N	N	N	G	G	N	G	G	N	F	G	G	F	G	G	G
Fusilade	N	G	G	G	N	N	G	N	N	N	N	N	N	N	N	N	N
Poast	N	G	G	G	N	N	G	N	N	N	N	N	N	N	N	N	N

G = Good F = Fair P = Poor N = None

** This table should be used only as a guide for comparing the relative effectiveness of herbicides to a particular weed. The response listed is based on using the maximum recommended rates for a particular herbicide under adequate and good growing conditions. If growers are getting satisfactory results under their conditions, they should not necessarily change products as a result of the information in this table.*

HERBICIDE LABEL RESTRICTIONS* ON VEGETABLE CROP ROTATIONS

Herbicide	Tomato[1]	Pepper	Snap Bean	Sweet Corn	Pumpkin	Melon[2]	Cole Crops[3]
Soybean or Tobacco Herbicides							
Canopy	10-B	18-B	18-B	18-B	18-B	18-B	18-B
Classic	10-B	30-B	12-B	18-B	18-B	18-B	18-B
Command	9-12[4]	NR	9	9	NR	9	12
Dual4	2	2	NR	NR	2	12	2
TriCor	4-10	18	18	18	18	18	18
Prowl	AH	AH	AH	AH	AH	AH	AH
Pursuit	18	18	NR	18	30	18	30
Reflex	18	18	NR	18	18	18	18
Roundup	NR	NR	NR	NR	NR	NR	NR
Scepter	18	18	11	18	18	18	18
Spartan	12	12	12	18	12	12	6[6]
Blazer or Status	AH	AH	AH	AH	AH	AH	AH
Corn Herbicides							
Aatrex	SY	SY	SY	NR	SY	SY	SY
Accent	10[5]	10[5]	10[5]	10	10[5]	10	10[5]
Beacon	18	18	18	8	18	18	18
Bicep	24	24	24	NR	24	24	24
Callisto	18	18	18	NR	18	18	18
Lightning	40	40	9.5	18	40	40	40
Permit	8	10	9	3	9	9	15-18
Princep	SY	SY	SY	NR	SY	SY	SY
Roundup	NR	NR	NR	NR	NR	NR	NR
Spirit	10	18	10	8	18	18	10[6]

** Waiting period (number of months after application) before the vegetable crop can be planted.*

[1] Transplanted tomatoes only.
[2] Muskmelons and watermelons.
[3] Broccoli, cabbage, and cauliflower.
[4] Depends on rate applied; consult label.
[5] 18 months with a soil pH of greater than or equal to 6.5.
[6] Cabbage only.

B: Field or soil bioassay should be conducted before planting the crop; consult label.
NR: No rotation restriction exists or herbicide labeled for the crop.
AH: After harvest—can be planted in fall or spring following application.
SY: The crop cannot be planted until the second year after application (cannot be planted the year following application).

***WARNING:** This information is for preliminary planning only! Follow manufacturer's instructions on product labels to determine the most up-to-date rotation restrictions and other special conditions that may apply.*

COMMON/TRADE NAMES OF HERBICIDES

Common Name	Trade Name
2,4-D amine	Several names
acetochlor	Surpass
alachlor	Micro-Tech, Partner
atrazine	Aatrex
bensulide	Prefar
bentazon	Basagran
bromoxynil	Buctril
carfentrazone	Aim
clethodim	Select
clomazone	Command
clopyralid	Stinger, Clopyr Ag
DCPA	Dacthal
dicamba	Clarity
dimethenamid-P	Outlook
diquat	Reglone
diuron	Karmex
EPTC	Eptam, Eradicane
ethalfluralin	Curbit, Sonalan
fluazifop-p	Fusilade DX
flumioxazin	Chateau
fluroxypyr	Starane
fomesafen	Reflex
glufosinate	Rely

Common Name	Trade Name
glyphosate	Roundup
halosulfuron	Permit, Sandea
imazamox	Raptor
imazethapyr	Pursuit
linuron	Lorox
mesotrione	Callisto
metolachlor	Dual Magnum
metribuzin	Tricor
napropamide	Devrinol
nicosulfuron	Accent
norflurazon	Solicam
oxyfluorfen	Goal
paraquat	Gramoxone
pendimethalin	Prowl
prometryn	Caparol
pronamide	Kerb
quizalofop	Assure II
rimsulfuron	Matrix
sethoxydim	Poast
terbacil	Sinbar
topramezone	Impact
trifluralin	Treflan

WEED SUSCEPTIBILITY OF SELECTED HERBICIDES LABELED FOR USE IN VEGETABLE CROPS

Herbicide	Weeds Controlled	
Basagran (bentazon)	Sedges	Yellow nutsedge
	Broadleaves	Canada thistle, purslane, lambsquarters, ragweed, galinsoga, jimsonweed, smartweed, velvetleaf, wild mustard, cocklebur
Buctril (bromoxynil)	Broadleaves	Mustard, cocklebur, pennycress, jimsonweed, annual morningglory, nightshade, lambsquarters, smartweed, pigweed
Command (clomazone)	Grasses	Barnyardgrass, crabgrass, fall panicum, foxtail, goosegrass, seedling johnson grass
	Broadleaves	Purslane, ragweed, jimsonweed, lambsquarters, smartweed, velvetleaf
Curbit (ethalfluralin)	Grasses	Annual bluegrass, crabgrass, barnyardgrass, foxtail, goosegrass, fall panicum, seeding johnson grass, shattercane, witchgrass
	Broadleaves	Wild buckwheat, carpetweed, chickweed, lambsquarters, pigweed, nightshade, purslane
2,4-D amine	Broadleaves	Carpetweed, dandelion, dock, galinsoga, pigweed, jimsonweed, lambsquarters, morningglory, plantain, ragweed, smartweed, thistle, wild mustard
Devrinol (napropamide)	Grasses	Barnyardgrass, crabgrass, goxtail, goosegrass, seedling johnson grass, panicum, annual bluegrass
	Broadleaves	Chickweed, purslane, common groundsel, prostrate knotweed, lambsquarters, pigweed, prickly lettuce
Dual II Magnum (s-metolachlor)	Grasses	Barnyardgrass, crabgrass, fall panicum, foxtail, goosegrass, witchgrass, yellow nutsedge
	Broadleaves	Nightshade, carpetweed, galinsoga, pigweed
Eptam (EPTC)	Grasses	Annual bluegrass, crabgrass, barnyardgrass, foxtail, goosegrass, shattercane, witchgrass
	Broadleaves	Annual morningglory, carpetweed, chickweed, lambsquarters, nightshade, purslane
Fusilade DX (fluazifop-P)	Grasses	Bermudagrass, goosegrass, johnson grass, wild proso millet, barnyardgrass, fall panicum, foxtail, crabgrass, witchgrass, volunteer cereals
Goal 2XL (oxyfluorfen)	Grasses	Barnyardgrass, weedy brome, crabgrass, foxtail, goosegrass, seedling johnson grass
	Broadleaves	Evening primrose, pigweed, common groundsel, purslane, black nightshade, shepherdspurse
Gramoxone Inteon (paraquat)	Grasses	Most annual grasses
	Broadleaves	Most annual broadleaves
Karmex, others (diuron)	Grasses	Barnyardgrass, crabgrass, annual bluegrass, foxtail
	Broadleaves	Pigweed, purslane, ragweed, chickweed, mustard, pennycress, velvetleaf

Continued On The Next Page

WEED SUSCEPTIBILITY OF SELECTED HERBICIDES LABELED FOR USE IN VEGETABLE CROPS *(continued)*

Herbicide	Weeds Controlled	
Kerb (pronamide)	Grasses	Barnyardgrass, brome, annual bluegrass, panicum, foxtail, goosegrass, volunteer small grains
	Broadleaves	Carpetweed, chickweed, henbit, knotweed, purslane, lambsquarters, nightshade, morningglory
Tricor (metribuzin)	Grasses	Downy brome, crabgrass, foxtail, seedling johnson grass
	Broadleaves	Pigweed, purslane, ragweed, chickweed, jimsonweed, lambsquarters, pepperweed, shepherdspurse, smartweed, prickly sida
Lorox (linuron)	Grasses	Barnyardgrass, crabgrass, fall panicum, goosegrass
	Broadleaves	Annual morningglory, carpetweed, groundsel, lambsquarters, mustard, cocklebur, pigweed, prickly sida, purslane, smartweed, velvetleaf
Micro-Tech (alachlor)	Grasses	Barnyardgrass, crabgrass, foxtail, goosegrass, fall panicum, witchgrass
	Broadleaves	Carpetweed, pigweed, galinsoga, nightshade, purslane
Poast (sethoxydim)	Grasses	Bermudagrass, goosegrass, johnson grass, quackgrass, wild proso millet, barnyardgrass, fall panicum, foxtail, crabgrass, witchgrass, volunteer cereals
Prefar (bensulide)	Grasses	Crabgrass, foxtail, fall panicum, goosegrass
Prowl (pendimethalin)	Grasses	Barnyardgrass, crabgrass, fall panicum, foxtail
	Broadleaves	Carpetweed, lambsquarters, pigweed, purslane
Pursuit (imazethapyr)	Broadleaves	Nightshade, pigweed, kochia, wild mustard
Roundup (glyphosate)	Grasses	Most annual and perennial grasses; see discussion of reduced tillage systems
	Broadleaves	Most annual broadleaves; see discussion of reduced tillage systems
Sandea (halosulfuron)	Sedges	Yellow nutsedge
	Broadleaves	Cocklebur, common lambsquarters, common ragweed, honeyvine milkweed, kochia, morningglory, nutsedge, pigweed, smartweed, velvetweed, wild mustard
Sinbar (terbacil)	Grasses	Crabgrass, foxtail, seedling johnson grass, barnyardgrass, annual bluegrass
	Broadleaves	Chickweed, lambsquarters, wild mustard, pepperweed, shepherdspurse, dandelion, knotweed, pigweed, purslane, plantain, ragweed, henbit, jimsonweed
Treflan (trifluralin)	Grasses	Annual bluegrass, crabgrass, barnyardgrass, foxtail, seedling johnson grass, goosegrass
	Broadleaves	Carpetweed, chickweed, knotweed, lambsquarters, pigweed, purslane

Disease Management

Vegetable crops can be affected by a number of diseases, often resulting in economic loss by reducing the quality and/or quantity of harvested produce. Managing diseases adds to grower input costs, reducing potential profits. Disease management programs, a necessity for most commercial growers, should maximize yield and quality while remaining cost effective.

Disease management practices and products are generally most effective as part of a preventative program. The rapid progression of plant diseases makes them difficult, if not impossible to control once established. To develop an effective management strategy, it is important to understand the diseases that can affect that crop, as well as the environmental factors that favor disease development.

Timely Diagnosis of Plant Diseases

Accurate and timely diagnosis is a critical step in disease management practice(s). Applying the wrong fungicide or cultural practices because of an incorrect diagnosis will result in poor disease control, wasted product and time, and continued yield losses.

Disease samples can be submitted to a local county Extension office for submission to the UK Plant Disease Diagnostic Lab. County Extension agents can provide assistance in collecting samples and background information needed for accurate diagnoses.

General Principles for Managing Plant Diseases

Most plant diseases are managed using a combination of cultural practices and fungicide applications. For management of most diseases, a single approach is rarely effective.

Exclusion

- Avoid introduction of pathogens into a planting:
- Buy or produce disease-free seeds and transplants.
- Carefully examine foliage, stems, roots, seeds, and bulbs of transplants for symptoms or presence of pathogenic propagules (infective structures such as spores). Only set healthy transplants into the cropping area, rejecting plant material that appears unthrifty or shows disease symptoms.

Planting and cultural practices

- Keep detailed records each growing season to identify problematic and recurring diseases.
- Select disease-resistant or tolerant cultivars, when available, based on site history. Choosing cultivars with resistance or tolerance reduces fungicide use and associated costs.
- Purchase clean seed from reputable dealers; saving seed from a previous crop is not recommended for large scale commercial producers.
- Provide adequate spacing to allow for air circulation. Poor air circulation can result in high humidity within plant canopies, prolonged leaf wetness, and soggy soils that can be conducive to disease development and pathogen spread. Row orientation and soil drainage can also affect plant environments.
- Follow cultural practices that promote plant health to enable plants to better resist diseases and stress-related problems. For example, water plants during drought, fertilize according to soil test results, and mulch (where appropriate) to maintain soil moisture and regulate soil temperatures.

Sanitation

- Employ sound sanitation practices to reduce sources of inoculum (overwintering structures, spores, bacterial cells, and virus particles, etc.) that can initiate disease.
- Eliminate (remove and destroy) diseased plants and plant material from fields.
- Move cull piles off the farm or as far as possible from production fields.
- Remove, disk, or chop crop residues immediately after harvest, followed by deep tillage to reduce populations of pathogens that can overwinter in plant debris.
- Do not compost diseased plant material or contaminated soil because incomplete composting may result in pathogen survival.
- Keep greenhouses clean and sanitize between crops.
- Equipment and tools should be disinfested after coming into contact with diseased plant material or infested soil. Bleach (10% solution), rubbing alcohol (70%), or a commercial sanitizer can be used to disinfest equipment and tools; rinse before storing to help prevent corrosion.
- Control weeds and insects. Certain diseases are spread by insects and may survive between crops in their insect vectors or in weeds. Timely weed and insect pest control is critical in these cases.

Crop rotation

Avoid planting the same crop species or closely related species in the same site. Rotate to a tolerant or resistant plant species or cultivar to reduce pathogen populations. Some pathogens can be reduced or eliminated with short rotations (1 to 2 seasons out of a crop group). However, longer intervals (3+ seasons) are often necessary for persistent pathogens like soilborne pathogens and nematodes.

Crops grouped together below are subject to the same disease and insect problems:

- Corn, sorghum, small grains, grasses
- Chives, garlic, leeks, onions, shallots
- Many herbs, including basil, lavender, oregano, rosemary, sage, peppermint, savory, thyme.
- Beets, Swiss chard, spinach
- Cabbage, cauliflower, kale, collards, Brussels sprouts, broccoli, kohlrabi, turnips, rutabaga, Chinese cabbage, mustard
- Peas, snap beans, lima beans, soybeans, clover, alfalfa

- Carrots, celery, celeriac, cilantro, cumin, dill, parsley, parsnips
- Pumpkins, squash, watermelons, cucumbers, muskmelons
- Endive, salsify, lettuce
- Potatoes, eggplant, tomatoes, peppers, tomatillo, tobacco

Monocots (cool- or warm-season grasses, cereals, corn, sweet corn, rye, and sorghum) are excellent crops to use in rotation with most vegetables.

Unfortunately, rotation is not effective against all diseases and crops. Some soilborne diseases (e.g., Rhizoctonia and Phytophthora diseases) have very wide host ranges and can affect several different groups. In addition, root and bulb crops—while often not related botanically—are susceptible to many of the same soilborne pathogens, so avoid other root crops and botanically related plants in a root/bulb crop rotation. Crop rotation will not impact diseases caused by airborne spores that come in from outside the field.

Fungicides

Timing fungicide applications is critical to their effectiveness. Fungicide applications must be made before infection. In general, fungicides prevent new infections and do not eradicate the pathogen or cure disease once infection has occurred. Fungicides may need to be reapplied at regular intervals due to weathering and to protect new growth.

Fungicides can be classified as contact or systemic. Contact fungicides remain on the surface of plant tissue, and they may be washed off by rain or irrigation. Systemic fungicides are absorbed into plant tissue and can move locally (e.g. from the top side of a leaf to the underside); this is called translaminar movement. Systemic fungicides can also be xylem mobile or fully mobile (xylem and phloem). Systemic fungicides are rainfast.

Fungicide persistence can also be improved using adjuvants. A variety of adjuvants can be combined with most (not all) fungicides, improving spread across plant surfaces, penetration into the plant cuticle, and/or adhesion onto plant surfaces. Read fungicide labels carefully to determine which, if any, adjuvants are recommended.

FRAC Codes

The Fungicide Resistance Action Committee (FRAC) has classified the active ingredients found in fungicides by their mode of action (target site) and assigned them a group number, called the "FRAC code." Fungicides with the same FRAC code have the same mode of action and essentially cause the same challenge to disease-causing organisms, even if they have different product names.

Rotating fungicides with different FRAC codes is an important aspect of preventing pathogens from developing resistance to any one specific fungicide. Avoiding back-to-back applications of fungicides that have very specific modes of action (such as strobilurins [FRAC 11] or sterol biosynthesis inhibitors [FRAC 3]) is especially important. The likelihood of developing resistance to these types of compounds is much greater than for broad spectrum materials (FRAC M) such as chlorothalonil, copper, or mancozeb. Fungicide products that are at risk for development of resistance will list specific resistance management guidelines on their label. Follow all label directions concerning alternating and mixing fungicides.

Use the product's FRAC code to determine how each fungicide fits into a season-long spray program. Careful adherence to resistance-management guidelines (rotating FRAC codes) will go a long way toward preventing or delaying the development of resistance. Refer to the "FRAC Code" table on pages 22-24 for a complete list of fungicides, their modes of action, and chemical classes.

Water Quality

Water quality is an important factor in fungicide performance, particularly the pH of the water source. Some products undergo a chemical degradation called alkaline hydrolysis when the pH is above 7. Likewise, there are fungicides that degrade when added to water with a low pH; these include most copper materials. The target pH for most vegetable fungicide applications is 6.5; buffering is typically needed if outside of a 6.0-7.0 range. Have water tested to avoid such problems, especially when using water from wells or ponds; the pH of these water sources can change through the growing season.

Additives

Adjuvants or surfactants should be used if the product label recommends them to ensure uniform coverage; these materials often include buffering agents. Do not use adjuvants unless the label indicates they are needed. Surfactants are most valuable in applications to cole crops and peppers because of their waxy leaf surfaces.

Time-of-Day

When possible, fungicide applications should be made when the air is still. With high pressure and tiny droplets, drift can be significant with even light breezes. Avoid applications during the 10 AM to 4 PM window of pollinator activity. In some cases, crop damage may result from fungicide applications made during hot, humid, or high-sunlight parts of the day.

Sprayer Configurations for Fungicides

A properly equipped and calibrated spray rig is just as important as the chemicals chosen for disease management. Accurate delivery translates to good coverage, and good coverage is essential for fungicides to perform to their maximum potential. The chemical must therefore be applied precisely to cover all microscopic surfaces of the foliage to protect against infection. Regardless of the type of sprayer used, they will need to be properly calibrated. Because of nozzle wear, recalibrations need to be done often when fungicides are used (see Appendix J).

Ground-operated spray equipment should be set to deliver 25 to 150 gallons per acre at 30 to 200 psi to ensure thorough coverage

of plant surfaces. Higher volumes are typically recommended for mature crops; higher pressures are often necessary for larger leaves or denser plantings. For protective fungicide applications, piston pumps and diaphragm pumps are best, although some roller pumps are also suitable.

Hollow-cone or twin-jet nozzles are preferred for fungicide applications. Two-piece cone nozzles (consisting of core and whirl plate-orifice disc) are best used with high pressures. The core is a fan-shaped insert that shapes the spray pattern; the orifice uses a small hole in a disc to control the volume that passes through at a given pressure. These components come in different sizes that can be used in different combinations to greatly impact delivery and coverage.

Spray nozzles are made from brass, stainless steel, polymers, and ceramic. Brass nozzles are relatively inexpensive but wear out quickly, requiring frequent replacement and recalibration of the rig. Ceramic nozzles have the longest life but can be expensive. Keep in mind that these nozzles won't need to be replaced as often as brass nozzles and will hold calibration longer because of reduced wear. Stainless steel nozzles are less expensive than ceramic nozzles and provide long service life as well.

The type of spray boom needed varies greatly from crop to crop. Ground crops such as melons and most crops early in the season can be sprayed effectively with a broadcast boom sprayer. During application, nozzles should be turned about 15 to 20 degrees towards the direction of travel (front) to achieve a more vigorous spray action and improve coverage. The change in angle reduces immediate contact with leaves (which block delivery) and increases the stirring of leaves/foliage (at high pressure). This aids in the coverage of the undersides of leaves and areas of leaf overlap. Sprayers used on upright crops such as staked tomatoes and peppers, however, should be modified with drop arms and multiple nozzles to achieve thorough coverage.

Air-blast sprayers and motorized backpack sprayers can be used successfully for many vegetable crops. Coverage should be evaluated using water-sensitive papers; as foliage becomes denser, spraying rows from both sides may become necessary with these types of equipment.

Vegetable Seed Treatments

Planting high-quality seeds that have been treated with fungicides will help achieve optimal control of seedling diseases. Most commercially available vegetable seeds are pre-treated with one or more fungicides and possibly an insecticide. Check the product packaging or with the seed dealer to find out what treatments have been applied. Most seed companies also sell untreated seed for use by organic growers or those who wish to apply their own seed treatments.

Growers who prefer to treat their own seed should see Appendix I for specific information on disinfection/disinfestation of vegetable seeds. Read and follow current product labels carefully. The majority of labeled seed treatments are restricted to commercial treatment only due to concerns about applicator exposure during seed treatment and handling. Do not treat seed that has already been treated by the seed company. If unsure how seed has been treated, contact the seed vendor. Never use chemically treated seed for food or feed.

Soil Fumigants for Control of Nematodes and Soilborne Diseases

Fumigation can be used as a management tool in commercial field plantings. However, fumigation is uncommon as a result of cost, regulations, and limited number of commercial applicators who provide the service to small growers. These fumigants, when applied properly, significantly reduce populations of soilborne pathogens and nematodes. Studies, however, have shown that the effect is temporary. Populations often return to damaging levels within a season in sites replanted with susceptible crops. Soil fumigants are dangerous to people and animals and should be used with extreme caution. Fumigation is not permitted for use in high tunnels in Kentucky.

Biopesticides

A number of products derived from plants, microorganisms, or from GRAS (Generally Recognized as Safe) chemistries are labeled for disease control in vegetable crops (see "Biopesticides" table on pages 25 and 26). Some of these products are effective under specific conditions, and others have limited disease-control potential. Many are not as effective as conventional fungicides. The Environmental Protection Agency (EPA), which labels agrichemicals, only evaluates biopesticide safety, but it does not test product efficacy. In addition, some of these "soft" products are not EPA-registered because they do not specifically claim to be pesticidal. These alternative products include living microorganisms (bacteria, viruses, fungi, nematodes, and protozoa), "natural chemicals," plant extracts, etc.

The Biopesticides table lists alternative products and provides some general information on these new materials, but this does not constitute a recommendation. Growers interested in these products should first test them in small-scale trials before changing from a recommended spray program. Many biopesticides are approved for greenhouse use; check product labels.

Post-Harvest Decays

Vegetable crops can suffer significant losses after harvest due to poor environmental conditions and microbes (bacteria and fungi) present in wounds and on produce surfaces. Proper post-harvest handling, precooling, storage, and packaging procedures are all disease-control practices that are essential to successful commercial vegetable production.

Chlorination washes or sprays can be used in reducing pathogen numbers and spread, as well as improving shelf life. The wash-water temperature should be about 10°F warmer than the internal temperature of the product being washed. This avoids microbes from being drawn into the tissues, which occurs when colder water is used.

Although chlorine can be added to wash water in several forms, the water pH must be adjusted so it is in the range of 6.5 to 7.5 to ensure that adequate chlorine is available and active. The following forms of chlorine are used in post-harvest water baths:

- Sodium hypochlorite 5.25% (household bleach)—use 13 to 17 fluid ounces per 100 gallons of water.
- Calcium hypochlorite (Magnum 65%)—use 1 ounce per 100 gallons of water; labeled for most vegetables as a dip and rinse.

For detailed information regarding post-harvest handling, storage, and care of fresh produce, including chlorination procedures, see the "Post-harvest and Food Safety" section of Appendix A.

Disease Management in Greenhouse Vegetable Crops

Sanitation and moisture control are the most important strategies for disease management in the greenhouse. Relatively few fungicides are labeled for use in greenhouses, and a limited number of resistant varieties is available. The table on pages 27 and 28 summarizes the fungicides and bactericides registered for use on greenhouse-grown vegetables (including transplants). Consult product labels for crops covered by each material and for application instructions.

- Disinfect surfaces and equipment using steam (180°F for 30 minutes) or commercial disinfectants to reduce carry-over pathogens.
- Do not produce vegetable transplants in greenhouses with tobacco or ornamental plants in order to avoid virus disease problems.

FUNGICIDE RESISTANCE ACTION COMMITTEE (FRAC) CODES

Product	FRAC Code	Active Ingredient	Chemical Group
These fungicide groupings now appear on most labels. The groupings are based on mode of action of the fungicides. The codes allow users to determine if different fungicides share the same mode of action. This information should be used by growers to prevent/delay the development of resistance by not overusing products with the same mode of action.			
Actigard	21	acibenzolar-S-methyl	SAR inducer
Acrobat	40	dimethomorph	CAA-Fungicides (carboxylic acid amides)
Affirm	19	polyoxin D zinc salt	chitin synthetase inhibitor
Aftershock	11	fluoxastrobin	QoI fungicide
Agri-Mycin 17	25	streptomycin	antibiotic
Ag Streptomycin			
Alude	33	Mono- and dibasic sodium, potassium, and ammonium phosphites	phosphonates
Amtide Propiconazole	3	propiconazole	DMI fungicide
Aproach	11	picoxystrobin	QoI fungicide
Aprovia Top	7/3	benzovindiflupyr + difenoconazole	carboxamide + DMI fungicide
Ariston	M/27	chlorothalonil + cymoxanil	inorganic + cyanoacetamide-oxime
Avaris	3/11	propiconazole + azoxystrobin	DMI + QoI
Badge SC	M	copper hydroxide + copper oxychloride	inorganic
Badge X2			
Basic Copper 53	M	basic copper sulfate	inorganic
Blocker 4F	14	PCNB	aromatic hydrocarbon
Blocker 10G			

(continued)

FRAC CODES *(continued)*

Product	FRAC Code	Active Ingredient	Chemical Group
Botran 75 W	14	dicloran	aromatic hydrocarbon
Botran 5F			
Bravo Ultrex	M	chlorothalonil	chloronitrile
Bravo WeatherStik			
Bravo ZN	M	chlorothalonil + zinc	chloronitrile
Bumper 41.8 EC	3	propiconazole	DMI fungicide
Cabrio	11	pyraclostrobin	QoI fungicide
Cannonball WP	12	fludioxonil	phenylpyrrole
Champ DP	M	copper hydroxide	inorganic
Champ Formula 2 FL			
Champ WG			
Chloronil 720	M	chlorothalonil	chloronitrile
Chlorothalonil 720 SC			
COC DF	M	copper oxychloride	inorganic
COC WP			
C-O-C-S WDG	M	copper oxychloride + basic copper sulfate	inorganic
Copper-Count-N	M	copper-ammonium complex	inorganic
Cueva	M	copper octanoate	inorganic
Cuprofix Ultra 40 Disperss	M	basic copper sulfate	inorganic
Cuprofix MZ Disperss	M	basic copper sulfate + mancozeb	inorganic + dithiocarbamate
Curzate 60 DF	27	cymoxanil	cyanoacetamide-oxime
Dexter Max	M/11	mancozeb + azoxystrobin	dithiocarbamate + QoI fungicide

(continued)

FRAC CODES *(continued)*

Product	FRAC Code	Active Ingredient	Chemical Group
Dithane F-45 Rainshield	M	mancozeb	dithiocarbamate
Dithane M-45			
Echo 720	M	chlorothalonil	chloronitrile
Echo 90 DF	M	chlorothalonil	chloronitrile
Elixir	M/M	mancozeb + chlorothanil	dithiocarbamate + chloronitriles
Elumin	22	ethaboxam	thiazole carboxamide
Emblem	12	fludioxanil	phenylpyrrole
Endura	7	boscalid	carboxamide
Equus 720 SST	M	chlorothalonil	chloronitrile
Equus DF			
Evergol Prime	7	penflufen	SDHI (succinate-dehydrogenase inhibitors)
Evito 480 SC	11	fluoxastrobin	QoI fungicide
Evito T	3/11	tebuconazole + fluoxastrobin	DMI + QoI fungicide
Flint	11	trifloxystrobin	DMI fungicide
Fontelis	7	penthiopyrad	carboxamide
Forum SC	40	dimethomorph	cinnamic acid
Fracture	n/a	BLAD	n/a
Gavel 75 DF	22/M	zoxamide + mancozeb	benzamide + dithiocarbamate
Gatten	U13	flutianil	thiazolidine
Gem	11	trifloxystrobin	QoI fungicide
Harbour	25	streptomycin	antibiotic
Headline	11	pyraclostrobin	QoI fungicide
Headline SC			
Headline AMP	11/2	pyraclostrobin + metconazole	QoI + DMI
Incognito	1	thiophanate-methyl	thiophanate
Initiate 720	M	chlorothalonil	chloronitrile
Inspire Super	3/9	difenoconazole + cyprodinil	DMI + anilinopyrimidine
Iprodione 4L AG	2	iprodione	dicarboximide
Kentan DF	M	copper hydroxide	inorganic
Kenja	7	isofetamid	carboxamide
Kocide 2000	M	copper hydroxide	inorganic
Kocide 3000			
Kocide 4.5 LF			
Kocide DF			
Koverall	M	mancozeb	dithiocarbamate
Luna Experience	7/3	fluopyram + tebuconazole	carboxamide + DMI fungicide
Luna Sensation	7/9	fluopyram + pyrimethanil	carboxamide + anilinopyrimidine
Luna Tranquility	7/9	fluopyram + pyrimethanil	carboxamide + anilinopyrimidine
ManKocide	M	copper hydroxide + mancozeb	inorganic + dithiocarbamate
Manzate Flowable	M	mancozeb	dithiocarbamate
Manzate Pro-Stick			
Manzate Max			
Mastercop	M	copper sulfate pentahydrate	inorganic

(continued)

FRAC CODES *(continued)*

Product	FRAC Code	Active Ingredient	Chemical Group
Mertect 340 F	1	thiabendazole	benzimidazole
MetaStar 2E AG	4	metalaxyl	phenylamide
Meteor	2	iprodione	dicarboximide
Micora	40	mandipropamid	mandelic acid
Miravis Prime	7/12	pydiflumetofen + fludioxonil	carboxamide + phenylpyrrole
Monsoon	3	tebuconazole	DMI fungicide
Mural	11/7	azoxystrobin + benzovindiflupyr	QoI fungicide + SDHI
Muscle	3/M	tebuconazole + chlorothalonil	DMI fungicide + chloronitrile
Nevado 4F	2	iprodione	dicarboximide
Nordox 75 WG	M	cuprous oxide	inorganic
Nu-Cop 3 L	M	copper hydroxide	inorganic
Nu-Cop 50 DF			
Nu-Cop 50 WP			
Nu-Cop 50 HB	M	cupric hydroxide	inorganic
Nufarm T-Methyl 4.5F	1	thiophanate-methyl	thiophanate
Nufarm T-Methyl 70 WSB			
Omega	29	fluazinam	2,6-dinitroaniline
Orondis Gold 200	49	oxathiapiprolin	oxysterol-binding protein modulator
Orondis Gold B	4	mefenoxam	phenylamide
Orondis Opti	M/49	chlorothalonil + oxathiapiprolin	chloronitrile + oxysterol-binding protein modulator
Orondis Opti B	M	chlorothalonil	chloronitrile
Orondis Ultra B	40	mandipropamid	mandelic acid
Orius 3.6F	3	tebuconazole	DMI fungicide
Onset 3.6F			
Pageant Intrinsic	7/11	boscalid + pyraclostrobin	carboxamide + QoI inhibitor
Penncozeb 75 DF	M	mancozeb	dithiocarbamate
Penncozeb 80 WP			
PhD	19	polyoxin D zinc salt	chitin synthetase inhibitor
Presidio	43	fluopicolide	benzamide
Previcur Flex	28	propamocarb	carbamate
Priaxor	7/11	fluxapyroxad + pyraclostrobin	carboxamide + QoI inhibitor
Pristine	7/11	pyraclostrobin + boscalid	QoI fungicide + carboxamide
Procure 480SC	3	triflumizole	DMI fungicide
Proline 480 SC	3	prothioconazole	DMI fungicide
Prolivo	U8	pyriofenone	methanone
Prosaro	3	prothioconazole + tebuconazole	DMI fungicide
Quadris	11	azoxystrobin	QoI fungicide
Quadris Opti	11/M	azoxystrobin + chlorothalonil	QoI fungicide + chloronitrile
Quadris Top	11/3	azoxystrobin + difenoconazole	QoI fungicide + DMI fungicide
Quash	3	metconazole	DMI fungicide

(continued)

FRAC CODES *(continued)*

Product	FRAC Code	Active Ingredient	Chemical Group
Quilt	3/11	azoxystrobin + propiconazole	QoI fungicide + DMI fungicide
Quilt Xcel	11/3	azoxystrobin + difenoconazole	QoI fungicide + DMI fungicide
Quintec	13	quinoxyfen	quinolene
Rally 40 WSP	3	myclobutanil	DMI fungicide
Ranman SC	21	cyazofamid	QiI fungicide
Reason 500 SC	11	fenamidone	QoI fungicide
Redigo 480	3	prothioconazole	DMI fungicide
Revus	40	mandipropamid	mandelic acid
Revus Top	40/3	mandipropamid + difenoconazole	mandelic acid + DMI fungicide
Rhyme	3	flutriafol	DMI fungicide
Ridomil Gold Bravo SC	4/M	mefenoxam + chlorothalonil	phenylamide + chloronitrile
Ridomil Gold Copper	4/M	mefenoxam + copper hydroxide	phenylamide + inorganic
Ridomil Gold GR	4	mefenoxam	phenylamide
Ridomil Gold MZ	4/M	mefenoxam + mancozeb	phenylamide + dithiocarbamate
Ridomil Gold PC GR	4/M	mefenoxam + PCNB	phenylamide + aromatic hydrocarbon
Ridomil Gold SL	4	mefenoxam	phenylamide
Rovral 4 Flowable	2	iprodione	dicarboximide
Scala	9	pyrimethanil	anilinopyrimidine
Shar-Shield PPZ	3	propiconazole	DMI fungicide
Stratego	3/11	propiconazole + trifloxystrobin	DMI fungicide + QoI fungicide
Stratego YLD	3/11	prothioconazole + trifloxystrobin	DMI fungicide + QoI fungicide
Sulfur	M	sulfur	inorganic

(continued)

FRAC CODES *(continued)*

Product	FRAC Code	Active Ingredient	Chemical Group
Switch	9/12	fludioxonil + cyprodinil	phenylpyrrole + anilinopyrimidine
Tanos	11/27	cymoxanil + famoxadone	cyanoacetamide-oxime + QoI fungicide
Tebu-Crop 3.6F	3	tebuconazole	DMI fungicide
Tebustar 3.6L			
Tebuzol 3.6F			
Terramaster	14	etridiazole	aromatic hydrocarbon
Thiophanate-Methyl 85 WDG	1	thiophanate-methyl	thiophanate
Tilt	3	propiconazole	DMI fungicide
Toledo	3	tebuconazole	DMI fungicide
Topaz	3	propiconazole	DMI fungicide
Topsin 4.5 FL	1	thiophanate-methyl	thiophanate
Topsin M 70 WP			
Topsin M WSB			
Torac	39	tolfenpyrad	methanone
Torino	U6	cyflufenamid	phenyl-acetamide
Ultra Flourish	4	mefenoxam	phenylamide
Uniform	4/11	azoxystrobin + mefenoxam	QoI fungicide + PA fungicide
Vibrance	7	sedaxane	SDHI
Velum Prime	7	fluopyram	carboxamide
Vertisan	7	penthiopyrad	carboxamide
Vivando	U8	metrafenone	methanone
Zampro	45/40	ametoctradin + dimethomorph	QxI inhibitor + cinnamic acid
Zing!	M/22	zoxamide + chlorothalonil	benzamide + chloronitrile
Ziram	M	ziram	dithiocarbamate

NON-FUMIGANT NEMATICIDES

Product	Product Amt/A	Application Method/Timing	Crops	Restricted Use	Re-Entry Interval (hrs)
Mocap 15G	13 to 80 lb	preplant broadcast or banded at-plant	beans (succulent), cabbage, cucumber, potato, sweet corn, sweetpotato	Yes	48
Mocap EC	2.4 to 6.9 fl oz /1,000 row-ft	preplant broadcast or banded at-plant	cabbage, potato, sweetpotato	Yes	48
Nemacur 3	2.33 qt	at-plant banded	eggplant	Yes	48
Nimitz	3.5 to 7 pt	preplant incorporated or drip irrigation	cucurbits, tomato, pepper, some cole crops, leafy vegetables	No	12
Velum Prime	6 to 6.84 fl oz	preplant in-furrow, post-emergence (drench, drip irrigation, and foliar)	suppression only on select cole crops, cucurbits, tomato, potato, sweetpotato	No	12
Vydate L	2 to 8 pt	preplant in-furrow, post-emergence (drip irrigation and foliar)	carrot, cucurbits, eggplant, pepper, sweetpotato, tomato	Yes	48

BIOPESTICIDES FOR VEGETABLE DISEASE MANAGEMENT

Product	Active Ingredient	Crops	Target Diseases/Pests	Greenhouse Use	Comments
Actigard	Acibenzolar-S-methyl	chili pepper, cucurbits, lettuce, onion, spinach, tomato	bacterial blights, downy mildew, powdery mildew; crop dependent—refer to label	No	Do not apply to plants stressed by heat, cold, or moisture extremes.
Biofence, Dominus	Allyl isothiocyanate	most vegetables (see label)	nematodes, root diseases	Yes	Read and follow label instructions for best efficacy.
Azaguard, Ecozin, Molt-X	Azadirachtin		nematodes	Yes	OMRI-listed.
Double Nickel	*Bacillus amyloliquefaciens* D747		powdery mildews, fungal leaf spots, root rots	Yes	OMRI-listed. May be applied through drip, as drench or transplant dip, or as foliar spray, depending on the target disease(s).
Stargus, Amplitude	*Bacillus amyloliquefaciens* F747		gray mold, white mold, downy mildew, root rots, Phytophthora, Pythium	Yes	OMRI-listed. May be applied through drip, as drench or transplant dip, or as foliar spray, depending on the target disease(s).
Serifel	*Bacillus amyloliquefaciens* MBI 600		fungal leaf spots, downy mildew, root rots	No	OMRI-listed. Do not use in greenhouse or transplant production. Use preventatively.
LifeGard	*Bacillus mycoides*		bacterial spot and speck, downy mildew, leaf spots, white mold	Yes	OMRI-listed. Use preventatively.
Ballad Plus, Sonata	*Bacillus pumilus* QST2808		Early blight, Late blight, downy mildew, powdery mildew, leaf blights, rust	Yes	OMRI-listed. Ballad Plus can be used on sweet corn only.
Companion	*Bacillus subtilis* GB03		root diseases	Yes	OMRI-listed.
Aviv	*Bacillus subtilis* IAB/BS03		fungal leaf spots, bacterial leaf spots, root rots	Yes	OMRI-listed.
Subtilex NG	*Bacillus subtilis* MBI 600	cucurbits, eggplant, pepper, tomato	root diseases, powdery mildew	Yes	Apply to soil or potting medium; use as a foliar spray for powdery mildew.
Cease, Serenade Max, Serenade ASO, Serenade Optimum, Serenade Soil, Minuet	*Bacillus subtilis* QST713	cole crops, leafy vegetables, legumes, cucurbits, pepper, tomato	downy mildew, powdery mildew, leaf blights	Yes	OMRI-listed.
Leap	*Bacillus thurigiensis* + methyl salicylate	tomato, pepper	bacterial diseases	Yes	Rotate with other chemistries labeled for bacterial disease management.
Fracture	Banda de *Lupinus albus* doce	tomato	powdery mildew, gray mold	Yes	Apply preventatively.
Majestene	*Burkholderia* spp. A396	cucurbits, eggplant, pepper, tomato, potato, sweetpotato, sweet corn	nematodes	Yes	OMRI-listed.

(continued on the next page)

BIOPESTICIDES *(continued)*

Active Ingredient		Crops	Target Diseases/Pests	Greenhouse Use	Comments
Romeo	Cerevisane	most vegetables (see label)	fungal leaf spots, downy mildews	Yes	OMRI-listed.
Contans WG	*Coniothyrium minitans*		Sclerotinia sclerotiorum (white mold, timber rot, drop)	Yes	OMRI-listed. Apply to soil or potting medium.
Pvent	*Gliocladium cantenulatum* J1446		seed rots, root diseases, Botrytis stem canker	Yes	-
SoilGard 12G	*Gliocladium virens* GL-21		seed rots, root diseases	Yes	OMRI-listed. Do not apply in conjunction with chemical fungicides.
ProAct, Messenger	Harpin protein	most vegetables (see label)	foliar diseases	n/a	-
Oxidate, Terracide	Hydrogen dioxide		root diseases, leaf blights	Yes	OxiDate is OMRI-listed.
Oxidate 2.0, TerraClean 5.0	Hydrogen dioxide + peroxyacetic acid		foliar and root diseases	Yes	OxiDate 2.0 is OMRI-listed.
Rendition	Hydrogen peroxide + peroxyacetic acid		foliar and root diseases	No	
Vacciplant	Laminarin		foliar and root diseases	Yes	Greenhouse use pre-transplant only. Use preventatively.
Ennoble	*Muscodor albus* SA-13		soilborne fungal diseases	Yes	OMRI-listed. Preplant soil biofumigant.
DiTera DF	*Myrothecium verrucaria*		nematodes	Yes	OMRI-listed.
Trilogy	Neem oil		foliar diseases	Yes	OMRI-listed. May cause leaf burn; test a small number of plants before spraying entire crop.
Mildew Cure	Oil (cottonseed, corn, and garlic)	pepper, tomato	bacterial spot, speck	Yes	May cause leaf burn; test a small number of plants before spraying entire crop.
Sporatec	Oil (clove, rosemary, thyme)	most vegetables (see label)	powdery mildew, fungal leaf blights	Yes	OMRI-listed. Addition of a spray adjuvant (spreader or penetrant) is recommended.
Oleotrol-M	Oil (soybean)		Botrytis gray mold, downy mildew, powdery mildew	Yes	OMRI-listed. Tank-mix with a spreader-sticker.
MeloCon WG	*Paecilomyces lilacinus*		nematodes	Yes	OMRI-listed.
AgriPhage	Phage		bacterial spot, speck	Yes	-
Alude, Fosphite, Fungi-Phite, Phostrol, ProPhyt, Rampart	Phosphorous compounds		downy mildew, powdery mildew, leaf blights	Yes	-
Affirm, OSO, PhD	Polyoxin D zinc salt	cucurbits, eggplant, tomato, pepper	powdery mildew, leaf spots	Yes	Apply preventatively.

(continued on the next page)

BIOPESTICIDES *(continued)*

Active Ingredient		Crops	Target Diseases/Pests	Greenhouse Use	Comments
Armicarb, Kaligreen, Milstop	Potassium bicarbonate	most vegetables (see label)	powdery mildew, fungal leaf blights	Yes	Kaligreen and Milstop are OMRI-listed. pH of spray solution should not be below 7.0.
M-Pede	Potassium salts of fatty acids		powdery mildew	Yes	Do not mix with surfactants or apply to stressed plants to avoid plant injury.
Sil-MATRIX	Potassium silicate		powdery mildew, Botrytis gray mold	Yes	OMRI-listed. Tank-mix with a non-ionic surfactant for best results.
Howler	*Pseudomonas chloroaphis*		fungal leaf diseases, root rots	Yes	OMRI-listed. Use preventatively.
Regalia	*Reynoutria sachalinensis*		powdery mildew, fungal leaf blights	Yes	OMRI-listed. First application should be made before symptoms appear.
Mycostop	*Streptomyces griseoviridis*		seedling, root, and stem rots	Yes	OMRI-listed. Can be added to potting mix or applied in-furrow to field soil.
Actinovate AG	*Streptomyces lydicus*		seedling, root, and stem rots; foliar blights	Yes	OMRI-listed. Can be used as a soil or foliar treatment.
T-22, RootShield, PlantShield	*Trichoderma harzianum*	cole crops, eggplant, leafy vegetables, pepper, tomato	seedling, root, and stem rots	Yes	OMRI-listed. Can be added to potting mix or applied in-furrow to field soil.
Bio-Tam 2.0	*Trichoderma* spp. strain ICC	cucurbits, leafy greens, pepper, tomato	seedling, root, and stem rots	Yes	OMRI-listed.
Binab	*Trichoderma viride*	most vegetables (see label)	seedling, root, and stem rots	Yes	-
BotryStop	*Ulocladium oudemansii* strain U3		gray mold, white mold	Yes	OMRI-listed.

FUNGICIDES AND BACTERICIDES FOR GREENHOUSE-GROWN VEGETABLES

Product	FRAC Code	Preharvest Interval (days)	Crops	Target Diseases	Comments
Labeled for Greenhouse Use[1]					
Blocker Flowable	14	n/a	beans, broccoli, Brussels sprouts, cabbage, cauliflower, pepper, tomato	Rhizoctonia root and stem rots, clubroot	Transplant production only. Apply as a drench to seedlings in beds or containers.
Botran 75 W	14	10	cucumber, lettuce (leaf), tomato	Botrytis blight and gray mold; white mold (cucumber)	Tomato: direct spray at stems; cucumber and lettuce: apply to foliage. Rates and application restrictions are crop-specific; see label.
Copper fungicides[3]	M	0	most vegetables (see label)	bacterial diseases, foliar blights, powdery mildew	-
Decree	17	0/3[2]	cucumber, tomato, pepper, leafy greens	gray mold (*Botrytis*)	Do not apply in field.
Emblem	12	0/7[2]	most vegetables (see label)	foliar diseases; stem, crown, and root rots	
Fontelis	7	0/1[2]	cucurbits, tomato	Alternaria diseases, Botrytis gray mold, powdery mildew, Sclerotinia diseases, Septoria diseases	-
Luna Tranquility	7/9	1	tomato only	fungal leaf spots	
Mancozeb (Dithane, Manzate, Penncozeb)	M	5/10[2]	most vegetables (see label)	foliar blights, bacterial diseases (+ fixed copper)	-
Micora	40	n/a	cole crops, leafy vegetables, eggplant, pepper, tomato	downy mildew, late blight	Use only on transplants grown for retail sale.
Pageant Intrinsic	11/7	0	tomato	Botrytis gray mold, fungal leaf spots	-

(continued on the next page)

FUNGICIDES AND BACTERICIDES FOR GREENHOUSE-GROWN VEGETABLES *(continued)*

Product	FRAC Code	Preharvest Interval (days)	Crops	Target Diseases	Comments
Previcur Flex[2]	28	5/7	cucurbits, lettuce (leaf), pepper, tomato	damping-off and root rot (*Pythium* spp. and *Phytophthora* spp.)	-
Ranman	21	n/a	basil, tomato	Pythium damping-off, downy mildew (basil)	Transplant production only. Only 1 application is permitted during growing cycle. Treat no later than 1 week before transplanting.
Scala SC	9	1	tomato, cucumber	early blight and Botrytis gray mold	Must be tank-mixed with another Early blight or Botrytis fungicide. Ventilate greenhouse for a minimum of 2 hours after application to avoid plant injury.
Spirato	12	0/7[2]	cole crops, cucurbits, herbs, tomato, pepper, leafy greens	fungal leaf spots	Rotate with a fungicide with a different mode of action.
Switch	9/12	0/7[2]	basil, beans, cole crops, cucurbits, pepper, tomato	fungal leaf diseases: early blight, Botrytis gray mold, and powdery mildew	Do not apply to cherry or grape tomatoes.
Terramaster 4EC	14	3	tomato	Pythium and Phytophthora root rots	Apply in drip irrigation or as a drench.
Terraguard	3	0	tomato and cucumber	powdery mildew	
Trionic	3	0/1[2]	cucumber, lettuce (leaf), tomato	powdery mildews, black spot	
Not Prohibited for Greenhouse Use[1]					
Agri-Mycin 17	25	n/a	pepper and tomato, celery	bacterial leaf spot, bacterial blight	Transplant production only.
Curzate 60DF	27	3	cucurbits, lettuce, tomato	downy mildew, late blight	-
Dexter Max	M/11	5/10[2]	broccoli, cabbage, cucurbits, lettuces, pepper, tomato	fungal leaf spots	Check label for potential compatibility issues.
Gavel	M/22	5	cucurbits, tomato	downy mildew, late blight	-
Inspire Super	3/9	0	cucumber only	Botrytis gray mold, powdery mildew	-
ManKocide	M	5/10[2]	most vegetables (see label)	foliar blights, bacterial diseases (+ fixed copper)	-
Procure	3	0/1[2]	cole crops, cucurbits, leafy greens	powdery mildew	Limited to 2 applications for cole crops and leafy greens; up to 4 applications for cucurbits.
Quadris Top	11/3	0/1[2]	cole crops, cucurbits, tomato	leaf mold, powdery mildew, Alternaria diseases	Do not use for transplant production.
Revus	40	1	beans, cole crops, cucurbits, lettuce, pepper	downy mildews	-
Revus Top	3/40	1	tomato	late blight, fungal leaf spots	-
RIdomil Gold MZ	4/M	5	tomato	late blight	-
Sulfur	M	0	cole crops, cucurbits, pepper, tomato	powdery mildew and fungal leaf spots	Check label for greenhouse compliance.
Tanos	11/27	3	cucurbits, pepper, tomato	downy mildew, late blight	Must be tank-mixed with mancozeb or copper fungicide.
Torino	U6	0	cucurbits	powdery mildew	-
Ziram	M	7	tomato	fungal leaf spots	-

[1] Pesticides may be used in greenhouses and high tunnels if the product label clearly states that greenhouse use is permitted (labeled) for a particular crop. Pesticides whose labels do not explicitly allow or prohibit greenhouse use may also be used as long as that particular pesticide is labeled for the crop to be treated and label instructions are followed—even though clear instructions for greenhouse use do not appear on the label.

[2] Crop dependent, see label.

[3] Greenhouse-approved copper fungicides include Badge X2, Champ DP, Champ Formula 2, Champ WG, Copper-Count-N, Cueva, Cuprofix, Kentan DF, Kocide 2000, Kocide 3000, Kocide DF, MasterCop, Nordox, Nu-Cop 50DF, and Nu-Cop HB. Badge X2, Champ WG, Cueva, Nordox, and Nu-Cop HB are approved for use in organic systems (OMRI-listed).

Asparagus

Lily family (Liliaceae): *Asparagus officinalis*

Planting and Culture

New asparagus plantings can be started as crowns or transplants. Fields to be planted with asparagus should be well drained, fairly level, free from rocks, and relatively weed-free.

Using 10- to 12-week-old transplants that have been started in the greenhouse is a good method for establishing a new planting. One-year-old crowns purchased from a plant producer is the traditional method of planting. Direct seeding into the field is not recommended. Furrows 5 to 6 inches deep are prepared for crowns or transplants. Problems associated with heavy rains filling in the furrows and smothering small transplants or direct-seeded plants make 1-year-old crowns the most reliable method.

One-year-old crowns should be planted in furrows with the buds up and 6 inches below the soil surface. Cover crowns with 1 ½ to 2 inches of soil at the time of planting. Furrows gradually are filled in as the spears begin growing.

Space crowns or transplants 14 to 18 inches apart in the furrow. Furrows should be 5 to 6 feet apart. You will need 5,808 plants per acre at 5-foot row spacing and 4,840 plants per acre at a 6-foot spacing.

Crowns should be planted in March or early April (see Appendix K). Transplanting should be done in late April or early May. See *Commercial Asparagus Production* (HO-66) for additional information.

Fertilizing

Apply fertilizer based on soil test results. Broadcast and disk in before establishing a new planting. Continue to apply fertilizer each year if needed. Apply animal manure or plow under a green manure cover crop before planting. Apply lime if needed to bring the soil pH to 6.5 to 6.8 and to supply calcium, deeply incorporating it prior to planting. Asparagus does not tolerate acid soils. Apply 200 pounds per acre of triple superphosphate (0-46-0) in the bottom of the trench just before planting. This is 2.3 pounds per 100 feet of row at a 5-foot spacing and 2.8 pounds per 100 feet of row at a 6-foot row spacing. This application is in addition to the phosphorus applied based on the soil test. Topdress an annual application of 70 to 75 pounds of nitrogen about two weeks before the end of the harvest season. Soil magnesium should be checked before planting and every three to four years after establishment.

Harvest

Harvest only five to six spears per plant if any the first year. After two years of growth, harvest for about 6 to 8 weeks in the spring in order to allow fern growth to develop for the rest of the season. Harvest spears when 5 to 10 inches long. Harvest during early morning hours and place in cold storage as soon as possible.

Cut asparagus spears to uniform length, tie in 2- to 2 ½-pound bunches and pack them in pyramid crates for the wholesale market.

Ferning out—feathering of the head of the asparagus spear—indicates poor quality with high fiber content. High temperatures will cause the tips of shoots to fern out at a shorter height.

After Harvest

After the final harvest, herbicides can be applied to help keep fern growth free from weed competition late in the season. It is important to keep the plants growing well after harvest until frost. The tops can then be mowed down with a rotary mower in the late winter or early spring before spear emergence.

VARIETIES: Asparagus

Varieties	Comments
Greenox (NJ-1122)	All-male hybrid, excellent yields, high disease resistance
Jersey Giant	All-male hybrid, vigorous plants, rust resistant, *Fusarium* tolerant
Jersey Knight	All-male hybrid, does well on heavier soils, high yielding, high disease tolerance
Jersey Supreme	All-male hybrid, uniform spear size, high disease tolerance
Millennium	Predominately male, Canadian variety, performs well in hot seasons, rust resistant
Porthos (NJ-1025)	All-male hybrid, new, top yielder, disease tolerance
Sequoia (NJ-1113)	New, elite all-male hybrid, top yielding variety, highly disease and rust tolerance
Pacific Purple	New Zealand variety, good for fresh eating, high yielding
Purple Passion	Sweet and tender, excellent taste
Walker Deluxe	All-male hybrid, high yield potential, resistance to rust and Fusarium

FERTILIZER: Asparagus

Soil Test Results (lb/A)		Fertilizer Needed (lb/A)
Phosphorus		**Phosphate (P_2O_5)**
Low	<31	121-240
Medium	31-60	61-120
High	61-80	21-60
Very High	>80	0-20
Potassium		**Potash (K_2O)**
Low	<201	201-300
Medium	201-300	101-200
High	301-450	51-100
Very High	>450	0-50
Nitrogen		**N**
		75

PESTICIDE SAFETY: Asparagus

	Signal[1]	Re-entry (hrs)	Harvest (days)
INSECTICIDES			
Assail 30 SG	C	12	1
Azera	W	12	0
Bt products	C	12	0
Coragen 1.67 SC	-	4	1
Dimethoate 4	W	48	180
Fulfill 50 WDG	C	12	170
Knack 0.86 EC	C	12	7
Malathion 57 EC	W	12	1
Radiant SC	C	4	60
Sevin XLR Plus	C	12	1
Transform 50 WG	D	24	180
Restricted Use			
Lannate 90 SP	DP	48	1
Permethrin 3.2 EC	C	12	1
FUNGICIDES			
Azoxystrobin[2]	C	4	100
Chlorothalonil[2]	C	12	190
Dexter Max	C	24	180
Dexter XCEL	C	24	180
Fixed coppers[2]	W	24/48	0
Elevate	C	12	180
Flint Extra	C	12	180
Mancozeb[2]	C	24	180
Mefenoxam[2]	C	48	1
Metalaxyl[2]	W	48	1
Myclobutanil[2]	W	24	180
Sulfur[2]	C	24	0
Tebuconazole[2]	C	12	180

1 W: Warning, C: Caution, D: Danger; P: Poison
2 Several formulations are marketed. See the general introduction for more details on fungicides.

INSECT CONTROL: Asparagus[1]

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
SPEAR TREATMENTS			
Armyworms			
Azera	16-56 fl oz	10 applications	Limit 1 application per day.
Bt products	See labels	-	-
Coragen 1.67 SC	3.5 to 7.5 fl oz	15.4 fl oz	Allow 3 days between applications.
Asparagus Beetles: Only the common asparagus beetle (blue and brown with white spots) injures the plants. Monitor plants in the early afternoon when beetles are active. Treat when 10% of the plants are infested with the beetles.			
Assail 30 SG	2.5 to 5.3 oz	2 applications	Allow 10 days between applications.
Azera	16-56 fl oz	10 applications	Limit 1 application per day.
Malathion 57 EC	1.5 to 2 pt	2 applications	Allow 7 days between applications.
Permethrin 3.2 EC	2 to 4 fl oz	16 fl oz	Allow 7 days between applications.
Sevin XLR Plus	1 qt	3 applications	Allow 3 days between applications.
Cutworms			
Permethrin 3.2 EC	2 to 4 fl oz	16 fl oz	Allow 7 days between applications.
Sevin XLR	1 qt	3 applications	Allow 3 days between applications.
FERN TREATMENTS			
Asparagus Beetles			
Assail 30 SG	2.5 to 5.3 oz	2 applications	Allow 10 days between applications. Controls Japanese beetle.
Azera	16-56 fl oz	10 applications	Limit 1 application per day.
Dimethoate 4	1 pt	2 pt	For post-harvest use only. Allow 14 days between applications.
Malathion 57 EC	1.5 to 2 pt	2 applications	Allow 7 days between applications
Permethrin 3.2 EC	4 fl oz	16 fl oz (3 app.)	Controls Japanese beetle.
Radiant SC	4 to 8 fl oz	24 fl oz	For post-harvest use only.
Sevin XLR	2 qt	5 applications	Controls Japanese beetle. Allow 3 days between applications.

1 Generic products available (Appendix G).

WEED CONTROL: Asparagus

Product Amt/A	lb A.I./A	Comments
ESTABLISHED BEDS ONLY		
0.5 to 1.92 fl oz Aim	0.008 to 0.03 Carfentrazone-ethyl	Post-emergence control of broadleaf weeds. Do not apply within 5 days of harvest. Do not apply more than 3.8 fl oz (0.06 pound a.i.) per acre per season. Do not make applications less than 20 days apart.
3.0 to 7.7 oz Callisto	0.09 to 0.24 mesotrione	Apply prior to spear emergence in spring or post-harvest or both. Can be applied broadcast in spring before spear emergence or banded post-harvest. Do not apply more than 7.7 fl oz/A per season. Use a NIS at 0.25% v/v if weeds are already emerged. Use of an adjuvant post-harvest may cause crop injury.
6.0 oz Chateau WDG	0.19 Flumioxazin	For pre-emergence control of weeds in dormant asparagus. Apply at least 2 weeks prior to asparagus emergence in spring or unacceptable crop injury will result. Apply no more than 6 oz/A for the entire season.
8 to 16 fl oz Clarity	0.25 to 0.5 dicamba	For control of broadleaf weeds. Do not cultivate within 7 days after application. Apply to actively growing weeds in 40 to 60 gal water immediately after a harvest but at least 24 hours before the next harvest. Use high rate for perennial weeds. Can be used in tank-mix with 2,4-D or Roundup for control of Canada thistle or field bindweed. Discard crooked spears after harvest. Maximum of 1 pt/A per year.
8 lb Devrinol 50 DF	4 napropamide	For control of annual grasses and broadleaves. Apply as a surface applied or incorporated treatment in 10 to 50 gal water/A to stands established at least 1 season. Do not allow contact with crop foliage. Apply before crop emergence in the spring and incorporate 1 to 2 inches. Rainfall or irrigation may be used for incorporation.
1.5 to 2 qt Formula 40 3.67L	1.38 to 1.84 2,4-D	For selective post-emergence control of broadleaf weeds only. Apply in 60 gal water/A to actively growing weeds, usually in April or May. If spears are present, treat immediately after cutting. Make no more than 2 applications (spaced at least 1 month apart) during harvest season. For post-harvest application, use drop nozzles to avoid spraying the fern.
2 to 4 lb Karmex XP	1.6 to 3.2 diuron	For pre-emergence control of annual grasses and broadleaf weeds. Apply 1 to 2 lb per acre on light sandy soils and 2 to 4 lb per acre on heavier soils. Apply after disking or chopping fern in the spring at least 4 weeks before spears emerge. A second application may be made at the end of the harvest season if rainfall is expected. Max. rate of 6 lb/A per year. 6 to 8 weeks of residual activity.
16 to 22 fl oz Roundup WeatherMax	0.56 to 0.77 glyphosate-salt	For non-selective post-emergence control of annual and perennial grasses and broadleaf weeds. Use only AMS 1 to 2% v/v. Adding a non-ionic surfactant can reduce weed control effectiveness. Solicam + Roundup tank-mix has been very effective against a broad spectrum of weed species. PHI = 14 days. Min. 30 days before replanting with any non-labeled crop. May be applied following final spring harvest, when all asparagus is cut to ground level over the entire planting, to help control both annual and perennial weeds.
1.5 lb Sinbar 80 WP	1.2 to 1.6 terbacil	For control of annual grasses and broadleaf weeds. Apply before spear emergence. Can be applied immediately after clean cutting.
2.5 to 5 lb Solicam DF	3 to 4 norflurazon	For control of annual grasses and broadleaf weeds and suppression of yellow nutsedge. Allow newly planted fields to become established for 1 season before 1st application. Apply as broadcast pre-emergent in min. 20 gal water/A. Apply in fall after chopping fern or in spring before fern emergence. Use low rate on sandy soils. PHI = 14 days. Apply only once per season.
3 to 4 pt Treflan HFP 4 E	1.5 to 2 trifluralin	For control of annual grasses and broadleaf weeds. Can be applied to dormant asparagus after fern has been removed or after last harvest. For split application, use 1.5 to 2 lb/A each time.
1.33 to 2.67 lb TriCor DF	1 to 2 metribuzin	For control of annual grasses and broadleaf weeds. Apply in 10 to 40 gal water/A before spear emergence. Do not use on young plants during the first growing season. Can also be applied as a split application of pre-emergence (0.67 to 1.33 lb/A) and after final harvest (1.33 to 2.0 lb/A) with a max. rate of 2.67 lb/A per season. PHI = 14 days.

(continued on next page)

WEED CONTROL: Asparagus *(continued)*

Product Amt/A	lb A.I./A	Comments
ESTABLISHED BEDS AND NEW PLANTINGS		
1 to 1.5 pt Fusilade DX	0.25 to 0.38 fluazifop-p	For selective post-emergence control of annual grasses and suppression of perennial grasses. Include 1% v/v crop oil or 0.25% v/v non-ionic surfactant/A. PHI = 1 day. Repeat applications must be at least 14 days apart. Max. rate is 48 fl oz/A per season and 24 fl oz/ application.
2 to 4 pt Gramoxone Inteon	0.69 to 1.38 paraquat salt	For non-selective contact kill of annual grasses and broadleaf weeds and top-kill of perennial weeds. Apply as a band treatment over the row or as broadcast pre-emergence in min. 10 gal water/A. In new seedlings apply before, during, or after planting but before emergence of the crop. In plantings established at least 2 years, apply min. 6 days before crop emergence or after last harvest. Use with non-ionic surfactant 0.25% v/v. Max. 3 applications/season. **Paraquat product labels require applicators to take an EPA-approved training every 3 years to mix, load, and apply paraquat.**
1 to 2 lb Lorox 50 DF	0.5 to 1 linuron	For control of annual grasses and broadleaves. Make 1 application pre-emergence at least 1 day before harvest. If used post-emergence, make 1 to 3 applications of 1 to 2 lb/A on weeds <4 inches tall. At the fern stage, apply 1 application of 4 lb/A as a directed spray to base of ferns. For newly planted crowns, use as pre-emergence application of 2 to 4 lb/A after planting. Activated charcoal as a band over the planted row is needed for protection of the newly planted crowns. For post-emergence, use 1 to 2 applications of 1 to 2 lb/A when ferns are 6 to 18 inches tall and weeds <4 inches tall. Do not exceed 4 lb/A per year.
0.5 to 2.5 pt Poast	0.09 to 0.49 sethoxydim	For control of actively growing grasses only. Use high rate on Johnson grass. Apply over the top of bearing asparagus with min. 1 day before harvest. Max. rate of 2.5 pt/ application and 5 pt/season.
2.4 to 8.2 pt Prowl H2O	1.14 to 3.90 pendimethalin	Not for use on newly seeded beds. Do not apply over the top of emerged spears. On sandy soils do not use more than 2.4 pt per acre. Do not apply more than 8.2 pt in a season. 14 day PHI.
16 to 22 fl oz Roundup WeatherMax 5.5L	0.69 to 0.94 glyphosate-salt	For non-selective post-emergence control of annual and perennial grasses and broadleaf weeds. Use only AMS 1 to 2% v/v. Adding a non-ionic surfactant can reduce weed control effectiveness. Do not apply within a week before first asparagus spears emerge. May be applied after the last harvest and all spears have been removed. If spears have been allowed to regrow, wait until ferns have developed and use a shielded spray in row middles. Solicam + Roundup tank-mix has been very effective against a broad spectrum of weed species. PHI = 14 days. Min. 30 days before replanting with any non-labeled crop.
0.5 to 1.5 oz Sandea 75 DF	0.023 to 0.072 halosulfuron	For weed control of broadleaf weeds and yellow nutsedge. May be applied post-emergence broadcast during the harvesting season in at least 15 gal water/A. After harvest, direct application below the ferns for complete weed coverage and avoid contact with the fern. Max. 2 applications/season and 2 oz/A per season. PHI = 1 day. For first-year transplants, apply at least 6 weeks after fern emergence.
9 to 16 fl oz Select Max	0.07 to 0.14 clethodim	Apply to actively growing grasses. Use NIS at 0.25% v/v. PHI = 1 day. Do not apply more than 16 fl oz/A in a single application and no more than 64 fl oz/A (0.5 lb ai/A) per season. Apply in a volume of at least 10 and no more than 40 gal/A. For repeat applications make on a minimum of a 14-day interval.

DISEASE CONTROL: Asparagus

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Cercospora Blight, Rust					
Chlorothalonil[4]					There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Bravo Ultrex	M	190	1.8 to 3.6 lb	11 lb	
Bravo Weather Stik	M	190	2 to 4 pt	12 pt	
Copper, fixed coppers[4, 6]					See label for rates, mixing instructions, and tank-mix precautions.
Dexter Max	M/11	180	2 to 2.2 lb	8.5 lb	Apply to ferns after harvest of spears.
Dexter XCEL	M/11/3	180	48 to 64 oz	192 oz	Apply to ferns after harvest of spears.
Dithane M45 and mancozeb[4]	M		2 lb	8 lb	Apply after harvest of spears. There are multiple Dithane formulations and mancozeb generics on the market. See label for rates.
Rally and myclobutanil[4] generics	3	180	5 oz	6 apps	Rust. Apply after harvest of spears.
Sulfur[4]	M	0			Rust. Phytotoxicity may occur when sulfur is applied when temperatures exceed 90°F.
Toledo and tebuconazole[4] generics	3	180	4 to 6 fl oz	3 apps	Rust.
Fusarium Crown Rot					
Dithane and mancozeb[4] generics	M				Pretreatment of crowns. See label for rate and directions.
Phytophthora Crown/Spear Rot					
Ridomil Gold SL and mefenoxam[4] generics	4	1	1 pt	2 pt	
MetaStar and metalaxyl[3] generics	4	1	2 qt		
Orondis Gold	U15	14	9.6 oz	2 apps	Crown soak, banded spray, or drip.
Stemphylium Purple Spot, Gray Mold					
Elevate	17	180	1.5 lb	4 apps	Gray mold.
Flint Extra	11	180	3.0 to 3.8 oz	11.6 oz	Stemphylium purple spot.
Quadris and azoxystrobin[4] generics	11	100	6.0 to 15.5 fl oz	4 apps	Stemphylium purple spot.

1 Products with numerical FRAC codes must be alternated or tank-mixed with products that have a different FRAC code to discourage resistance development. See product label for maximum number of consecutive applications allowed. Refer to the table on pages 22-24 for more information on FRAC codes.

2 Pre-harvest interval.

3 Per 100 gallons of water.

4 Generic products available (Appendix F). Amounts and seasonal limits per acre are product dependent.

5 Use higher rate when pressure is severe.

6 Fixed coppers labeled in KY include: Badge SC, Badge X2, Basic Copper 53, Champ, Champ WG, ChampION++, C-O-C-S WDG, Cueva, Cuprofix, Cuproxat, Kentan, Kocide 2000, Kocide 3000, Kocide DF, KOP-5, MasterCop, Nordox 75 WG, Nu-Cop 30 HB, Nu-Cop 50DF, Phyton 27, Phyton 35, and Previsto. Rates may vary by product and by crop. Refer to specific product label for this information.

Beans

Pea family (Fabaceae): *Phaseolus vulgarus*—snap bean, *P. lunatus*—Lima bean, *Glycine max*—soybean

Planting and Culture

Begin first plantings after danger of frost and once soil has warmed to 60 to 65°F (see Appendix K). Successive plantings of bush snap beans at two- to three-week intervals may be desirable for roadside markets, U-pick, farmers' markets, and shipping.

Bush Beans. Plant in rows 24 to 30 inches apart. Plant seeds 2 to 3 inches apart in the row and 1 ½ inches deep in a well-prepared seedbed. Also see, "Production with Plasticulture."

Lima Beans. Plant in rows 24 to 30 inches apart for bush lima beans and 5 feet apart for pole lima beans. Space seeds 3 to 5 inches in the row, 1 to 2 inches deep.

Pole Beans. Plant seed in rows and thin plants to 6 to 8 inches apart in the row. Sow seed 1 to 2 inches deep. Space rows 5 feet apart, and prepare a wire trellis for plants to grow on.

Dry Beans (pea-beans). Plant seed in rows 28 inches apart with seed spaced 2 to 3 inches apart in the row and 1 inch deep. The first plantings should be made after danger of the last killing frost in the spring. Beans will not withstand frost and do not do well when planted in cold soils, which make them more susceptible to rotting and slow growth. A seed treatment is highly recommended. Successive plantings of bush beans at two- to three-week intervals can be made until August 15.

Seeding rate is partly determined by variety. Small-seeded varieties require fewer pounds of seed per acre than large-seeded varieties. The average amount of seed to plant is about 80 pounds per acre.

There are no known detrimental effects on plant growth associated with inoculating seed with *Rhizobium* prior to planting. However, there are many different strains of *Rhizobium,* and many factors are involved in determining if it will increase nitrogen fixation and help your crop. There will be no effect if the field has a recent history of being planted with beans, because a large population of *Rhizobium* will already be present in the field.

Production with Plasticulture

Some Kentucky growers producing for roadside stands or farmers' markets have obtained extremely high yields and a cleaner harvest of bush beans and half runners using trellises and black plastic on raised beds with drip irrigation. Holes are punched in the plastic by hand or with a waterwheel setter, and two to three seeds are planted in each hole. Two rows about 15 inches apart are planted on each bed with a spacing of 12 inches between planting holes in the row. A simple trellis can be constructed by stringing horizontal rows of twine between tomato stakes spaced about 8 to 10 feet apart. Horizontal stringing is followed by weaving twine vertically between the top and bottom horizontal lines.

Pole beans require sturdier trellises. High-tensile wires are strung at 6 inches and at 5 feet above the ground. Jute twine is then woven vertically between these two wires.

Fertilizing and Pollination

Snap-bean fertilizer trials in Kentucky indicate that 50 pounds of actual nitrogen per acre and a pH of 6.2 to 6.5 is adequate for good yields. For beans grown on plastic with drip irrigation, 19 to 26 pounds of calcium nitrate per acre can be fertigated weekly.

Zinc deficiency has been a limiting factor in some areas of the state. Where zinc levels are known to be low, up to 20 pounds of elemental zinc or 55 pounds per acre of zinc sulfate should be broadcast prior to seeding (see Appendix B).

If air temperature rises above 90°F during the pollination period, pollen production and growth can be reduced. Unpollinated blossoms will drop off. Blossom drop can be reduced by maintaining adequate soil moisture and by keeping good leaf growth on the vines. Poor pollination also can cause pods to be misshapen. Irrigation at the time of bloom will help ensure good pod set if soils are dry.

Harvesting and Storage

For the best eating quality, harvest green snap beans and pole beans when the bean seed is about one-third developed. Many snap beans are mechanically harvested (once-over harvest). Varieties that produce a concentrated set of pods should be grown where mechanical harvesters are used. Green beans for the fresh wholesale market are packed in bushel baskets or cartons.

Vegetable soybeans (edamame) are picked when the pods are nearly fully grown but before they begin to turn yellow. Shelling is made easier by dropping the pods in a pot of boiling water for 15 to 20 minutes.

Navy and kidney beans should be harvested and handled at the 17 to 18 percent moisture level to prevent splitting and seed-coat damage. Pinto beans should be harvested at around 14 percent moisture.

Green beans are stored at 40° to 45°F and 90 to 95 percent relative humidity.

VARIETIES: Beans

Variety	Use			Seed Color[1]	DTM[2]	Comments
	Fresh Market	Canning	Shipping			
SNAP BEANS, BUSH PLANT TYPE						
Bronco	X	X	X	W	53	Round, 5.5 inches long, dark green pods, high yield potential, resistance to mosaic and seed transmission of bean common mosaic virus.
Tema	X	X		DBr	53	Round pods, resistance to mosaic and seed transmission of bean common mosaic virus.
Colter	X	X	X	W	53	Round pod, early maturing, medium-dark green, good heat set tolerance, high resistance to bean common mosaic virus, curly top virus and rust.
Lewis	X	X	X	W	53	Resistant to bean common mosaic and curly top viruses rust, halo blight, bacterial brown spot.
Hickok	X	X			54	Upright plant; high quality and straight pods; has grown well in both northern and southern U.S. Some resistance to bean common mosaic virus, rust, and bean curly top virus.
Bowie	X		X	W	54	Round pod, dark green, highly tolerant to common bean mosaic virus, beet curly top virus, halo blight; Intermediate resistance to bacterial brown spot.
Orient	X			W	55	Round 4 inch medium green slim pods, specialty bean, very good flavor, highly resistant to common bean mosaic virus, halo blight, intermediate resistance to bacterial brown spot.
Magnum	X		X	LBr	55	Flat, medium light green, 6.9 inches long pods, resistance to mosaic and seed transmission of bean common mosaic virus.
Caprice	X		X	W	56	Round pods, 6 inches, medium green, resistant to bean common mosaic virus, Anthracnose, halo blight, common blight, with some resistance to bacterial brown spot.
BA0958	X		X	W	57	Round pod, bean contains extra fiber to prevent breakage, improve appearance and shelf life, good for machine harvest, tolerant to common bean mosaic virus, intermediate tolerance to brown spot.
Roma II (snap bush Romano)	X			W	58	Resistant to common bean mosaic and NY15 mosaic. Flat pods.
Jade II	X	X	X	W	60	Round pods, high quality, dark green, high yielding, resistant to bean common mosaic virus, intermediate resistance common rust.
SNAP BEANS, POLE TYPE						
Kentucky Blue	X	X	X	W	58	Round, medium green pod, 7 to 10 inches long, excellent flavor; resistant to bean common mosaic virus, rust.
Kentucky Wonder 191	X	X	X	W	65	Round pod; rust resistant.
State Half Runner	X	X		W	60	Some tolerance to common bean mosaic; beans have strings, poor set in heat
Volunteer Half Runner	X	X		W	60	Resistant to common bean mosaic, intermediate resistance to rust, sets better than others in heat
OTHER						
Furano	X				54	Flat 5 ½ inch medium green attractive pods, low fiber, high yielding, highly resistant to common bean mosaic virus
Royal Burgundy	X			B	55	Deep purple snap beans on bush plants.
Maxibel	X			T/B	60	Long, thin, stringless 7 to 8 inches "French beans."
Carson (bush)	X			W	56	Round, yellow wax bean; resistant to bean common mosaic virus, NY15 mosaic, bacterial spot, 5 to 6 inches long.
Fordhook 242 (Lima, bush)		X	X	G	78	Large pod; sets blossom under adverse weather conditions.
VEGETABLE SOYBEANS						
Envy	X			Y/G	75	Earliest vegetable bean; 2 foot tall plant
BeSweet 292	X			Y/G	85	Top commercial variety; powdery mildew resistant.

1 W = white, DBr = dark brown, LBr = light brown, T/B = tan/brown, Y = yellow, G = greenish

2 Days to maturity

FERTILIZER: Beans

Soil Test Results (lb/A)		Fertilizer Needed (lb/A)
Phosphorus		**Phosphate (P_2O_5)**
Low	<31	51-95
Medium	31-60	1-50
High	>60	0
Potassium		**Potash (K_2O)**
Low	<201	51-150
Medium	201-300	1-50
High	>300	0
Nitrogen		**N**
Poor soils		50
Heavily fertilized soils		20-30

PESTICIDE SAFETY: Beans

	Signal[1]	Re-entry (hrs)	Harvest (days)
INSECTICIDES			
Acramite 4SC	C	12	3/7[3]
Admire Pro	C	12	7/21[3]
Assail 30 SG	C	12	7
Avaunt eVo 30 DG	C	12	3/7[3]
Beleaf 50 SG	C	12	7
Blackhawk 36 WG	C	4	3/28
Bt products	C	12	0
Coragen 1.67 SC	-	4	1
Courier 40 SC	W	12	14
Dibrom 8	D	24	1
Dimethoate 4 E	W	48	0
Exirel 0.83 SE	C	12	1/7[3]
Intrepid 2F	C	4	7
Kanemite 15 SC	C	12	7
Knack 0.83 EC	C	12	7
Magister SC	W	12	7
Malathion 8	C	12	1
Miteus 0.42 EC	W	21	1
Movento 2 SC	C	24	1
Orthene 97 S	C	24	1/14[3]
Portal 0.4 EC	W	12	1
Radiant SC	C	4	3/28[3]
Rimon 0.83 EC	W	12	1
Sevin XLR Plus	C	12	3
Sivanto Prime 1.67 SL	C	12	7/21[3]
Transform 50 WG	D	24	7
Trigard 75 WP	C	12	7
Vantacor 5 SC	-	4	1
Verimark 1.67 SC	-	4	AP
Restricted Use			
Agri-Mek 0.7 SC	W	12	7[3]
Asana XL	W	12	3/21[3]
Baythroid XL	W	12	3/7[3]
Brigade 2 EC	W	12	3
Diazinon 50 W	C	24	7
Fastac 0.83 EC	D	12	1/21[3]

(continued)

PESTICIDE SAFETY: Beans *(continued)*

	Signal[1]	Re-entry (hrs)	Harvest (days)
Lannate 90 SP	DP	48	1/14[3]
Mustang Maxx	W	12	1/21[3]
Proaxis 0.5 EC	C	24	7/21[3]
Thimet 20 G	DP	48	60
Warrior II	W	24	7/21[3]
FUNGICIDES[3]			
Aproach	C	12	14
Aprovia Top	C	12	14
Azoxystrobin[2]	C	4	0
Botran	C	12	2
Blocker 10G	C	12	45
Cannonball WP	C	12	7
Chlorothalonil[2]	W	12	7/14[3]
Endura	W	12	7/21[3]
Fixed coppers[2]	W	24/48	0
Fontelis	C	12	0
Headline	W	12	7/30[3]
Iprodione[2]	C	24	0
Kenja	C	12	7/30[3]
Luna Experience	C	12	14
Mefenoxam[2]	C	48	0
Metalaxyl[2]	W	48	0
Omega 500F	W	12	30
PCNB[2]	W	12	0
Priaxor	C	12	7/21[3]
Propiconazole[2]	C	12	3
Propiconazole + Azoxystrobin[2]	W	12	7/14[3]
Quadris Opti	W	12	14
Quadris Top	C	12	14
Quilt	W	12	7/14[3]
Quilt Xcel	W	12	7/14[3]
Ranman	C	12	0
Reason	C	12	3
Sulfur[2]	C	24	0
Switch	C	12	7
Tebuconazole[2]	C	12	7/14[3]
Thiophanate-methyl[2]	C	12	14/28[3]
Trevo Packed	C	24/72	14/28[3]
Vertisan	C	12	21
Snap beans only			
Botran 75 W	C	12	2
Botran 5F	C	12	2
Myclobutanil[3]	W	24	0
Dry beans only			
Muscle	C	12	14
Quadris Opti	W	12	14
Quash	C	12	21
Proline 480 SC	C	48	7

1 W: Warning, C: Caution, D: Danger; P: Poison
2 Several formulations are marketed. See the general introduction for more details on fungicides.
3 Dependent on formulation, type of bean, and application rate; there are specific restrictions on feeding and grazing, so see label.

INSECT CONTROL: Beans[1]

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
PREPLANT INCORPORATED			
Cutworms: Eliminate weeds from field margins and plow fields at least 2 weeks before planting to destroy cutworm food sources and egg laying sites.			
Diazinon AG 500	2 to 4 qt	1 application	Incorporate immediately. Also for wireworms.
AT PLANTING			
Aphids, Leafhoppers, Seedcorn Maggots: Seedcorn maggots damage newly planted seeds by feeding on seed contents. Shallow planting in well-prepared seedbeds and adequate soil temperature to promote rapid germination will aid in reducing problems. Heavy cover crops or manure should be plowed early to render fields less attractive for egg laying.			
Admire Pro	7 to 10.5 fl oz	10.5 fl oz	See label for application methods.
Thimet 20 G	4.5 to 7 oz/ 1,000 row-feet	1 application	Place band on each side of furrow.
FOLIAR TREATMENTS			
Grasshoppers			
Asana XL	5.8 to 9.6 fl oz	38.4 fl oz	Do not feed to livestock.
Baythroid XL	2.4 to 3.2 fl oz	6.4 fl oz	Limit 3.2 fl oz per 14-day period. For shelled beans only.
Brigade 2 EC	2.1 to 6.4 fl oz	12.8 fl oz	Allow 3 days between applications. Dried beans only.
Coragen 1.67 SC	2 to 5 fl oz	15.4 fl oz	Allow 3 days between applications.
Dimethoate 4 E	8 to 16 fl oz	32 fl oz	Do not spray during bloom. Allow 14 days between applications.
Mustang Maxx	3.2 to 4 fl oz	24 fl oz	Allow 5 days between applications.
Aphids, Leafhoppers			
Admire Pro	1.2 fl oz	3.6 fl oz	Allow 7 days between applications.
Asana XL	2.9 to 9.6 fl oz	38.4 fl oz	Do not feed to livestock. For leafhoppers only.
Assail 30 SG	2.5 to 5.3 oz	16 oz	Limit 3 applications. Allow 7 days between applications. Not for dried beans.
Baythroid XL	0.8 to 1.6 fl oz	6.4 fl oz	Limit 3.2 fl oz per 14-day period. For shelled beans only.
Beleaf 50 SG	2.8 oz	8.4 oz	Limit 3 applications. Allow 7 days beteeen applications.
Brigade 2 EC	1.6 to 6.4 fl oz	12.8 fl oz	Allow 3 days between applications. Dried beans only.
Dimethoate 4 E	8 to 16 fl oz	32 fl oz	Do not spray during bloom. Allow 14 days between applications.
Lannate 90 SP	0.5 to 1 lb	5 lb	Limit 10 applications.
Movento 2 SC	4 to 5 fl oz	10 fl oz	Allow 7 days between applications. Requires surfactant. For aphids.
Mustang Maxx	2.72 to 4 fl oz	24 fl oz	Allow 5 days between applications.
Orthene 97 S	0.5 to 1 lb	2.12 lb	Allow 3 or 7 days between applications, rate dependent. Not for green beans.
Proaxis 0.5 EC	2.56 to 3.84 fl oz	15.36 fl oz	Allow 5 days between applications.
Sevin XLR Plus	1 qt	6 qt (4 app.)	Leafhoppers only. Not for shelled beans. Allow 7 days between sprays.
Sivanto Prime 1.67 SL	7 to 14 fl oz	28 fl oz	Allow 10 days between applications.
Transform 50 WG	0.75 to 1 oz	8.5 oz	Only apply after petal fall. Allow 14 days between applications. For aphids.
Warrior II	1.28 to 1.92 fl oz	7.68 fl oz	Allow 5 days between applications.
Corn Earworms			
Asana XL	5.8 to 9.6 fl oz	38.4 fl oz	Do not feed to livestock.
Avaunt eVo 30 DG	3.5 to 6 oz	24 oz	Allow 7 days between applications. Limit 4 applications.
Baythroid XL	2.4 to 3.2 fl oz	6.4 fl oz	Limit 3.2 fl oz per 14-day period. For shelled beans only.
Blackhawk 36 WG	2.2 to 3.3 oz	20 oz	Allow 5 days between applications.
Brigade 2 EC	2.1 to 6.4 fl oz	12.8 fl oz	Allow 3 days between applications. Dried beans only.
Coragen 1.67 SC	3.5 to 7.5 fl oz	15.4 fl oz	Allow 3 days between applications.
Exirel 0.83 SE	10 to 20.5 fl oz	61.5 fl oz	Allow 5 days between applications.
Fastac 0.83 EC	2.7 to 3.8 fl oz	11.4 fl oz	Allow 5 days between applications.
Intrepid 2 F	10 to 16 fl oz	64 fl oz	Allow 7 days between applications.
Mustang Maxx	2.72 to 4 fl oz	24 fl oz	Allow 5 days between applications.
Orthene 97 S	0.75 to 1 lb	2.12 lb	Allow 3 or 7 days between applications, rate dependent. Not for green beans.
Proaxis 0.5 EC	2.56 to 3.84 fl oz	15.36 fl oz	Allow 5 days between applications.
Radiant SC	4 to 8 fl oz	12/28 fl oz	Allow 4 days between applications. Seasonal limit based on bean type.
Warrior II	1.28 to 1.92 fl oz	7.68 fl oz	Allow 5 days between applications.

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INSECT CONTROL: Beans[1] *(continued)*

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Cutworms			
Baythroid XL	0.8 to 1.6 fl oz	6.4 fl oz	Limit 3.2 fl oz per 14-day period. For shelled beans only.
Fastac 0.83 EC	1.3 to 3.8 fl oz	11.4 fl oz	Allow 5 days between applications.
Mustang Maxx	1.28 to 4 fl oz	24 fl oz	Allow 5 days between applications.
Orthene 97 S	0.5 to 1 lb	2.12 lb	Allow 3 or 7 days between applications, rate dependent. Not for green beans.
Proaxis 0.5 EC	1.92 to 3.2 fl oz	15.36 fl oz	Allow 5 days between applications.
Warrior II	0.96 to 1.6 fl oz	7.68 fl oz	Allow 5 days between applications.
Japanese Beetles			
Baythroid XL	2.4 to 3.2 fl oz	6.4 fl oz	Limit 3.2 fl oz per 14-day period. For shelled beans only.
Brigade 2 EC	2.1 to 6.4 fl oz	12.8 fl oz	Allow 3 days between applications. Dried beans only.
Fastac 0.83 EC	2.7 to 3.8 fl oz	11.4 fl oz	Allow 5 days between applications.
Mustang Maxx	2.72 to 4 fl oz	24 fl oz	Allow 5 days between applications.
Proaxis 0.5 EC	2.56 to 3.84 fl oz	15.36 fl oz	Allow 5 days between applications.
Sevin XLR Plus	0.5 to 1 qt	6 qt	Not for shelled beans. Limit 4 applications. Allow 7 days between applications.
Warrior II	1.28 to 1.92 fl oz	7.68 fl oz	Allow 5 days between applications.
Mexican Bean Beetles, Bean Leaf Beetles: Treat for Mexican bean beetle if populations exceed 0.5 adults per plant or if egg mass number is greater than 1 per foot of row.			
Asana XL	2.9 to 5.8 fl oz	38.4 fl oz	Do not feed to livestock. Bean leaf beetle only.
Assail 30 SG	2.5 to 5.3 oz	16 fl oz	Limit 3 applications. Allow 7 days between applications. Not for dried beans.
Baythroid XL	2.4 to 3.2 fl oz	6.4 fl oz	Limit 3.2 fl oz per 14-day period. For shelled beans only.
Brigade 2 EC	2.1 to 6.4 fl oz	12.8 fl oz	Bean leaf beetle only. Allow 3 days between applications. Dried beans only.
Dimethoate 4 E	8 to 16 fl oz	2 pt	Do not spray during bloom. Allow 14 days between applications.
Fastac 0.83 EC	2.7 to 3.8 fl oz	11.4 fl oz	Allow 5 days between applications.
Mustang Maxx	2.72 to 4 fl oz	24 fl oz	Allow 5 days between applications.
Orthene 97 S	0.5 to 1 lb	2.12 lb	Allow 3 or 7 days between applications, rate dependent. Not for green beans.
Proaxis 0.5 EC	1.92 to 3.2 fl oz	15.36 fl oz	Allow 5 days between applications.
Rimon 0.83 EC	9 to 12 fl oz	36 fl oz	Allow 7 days between applications.
Sevin XLR Plus	0.5 to 1 qt	6 qt	Not for shelled beans. Limit 4 applications. Allow 7 days between applications.
Warrior II	0.96 to 1.92 fl oz	7.68 fl oz	Allow 5 days between applications.
Spider Mites			
Acramite 4 SC	16 t0 24 fl oz	2 applications	Allow 14 days between applications.
Agri-Mek 0.7 SC	1.75 to 3.5 fl oz	10.5 fl oz	Allow 6 days between applications. Must use non-ionic surfactant.
Brigade 2 EC	5.12 to 6.4 fl oz	12.8 fl oz	Allow 3 days between applications. Dried beans only.
Kanemite 15 SC	31 fl oz	62 fl oz	Allow 14 or 21 days between applications, depending on bean type.
Magister SC	32 to 36 fl oz	36 fl oz	Limit 1 application.
Miteus 0.42 EC	2 pt	4 pt	Allow 14 days between applications. For snap beans only. Two applications only.
Portal 0.4 EC	2 pt	4 pt	Allow 14 days between applications. For snap beans only. Two applications only.
Stink Bugs			
Baythroid XL	1.6 to 2.4 fl oz	6.4 fl oz	Limit 3.2 fl oz per 14-day period. For shelled beans only.
Brigade 2 EC	2.1 to 6.4 fl oz	12.8 fl oz	Allow 3 days between applications. Dried beans only.
Fastac 0.83 EC	3.2 to 3.8 fl oz	11.4 fl oz	Allow 5 days between applications.
Mustang Maxx	3.2 to 4 fl oz	24 fl oz	Allow 5 days between applications.
Proaxis 0.5 EC	2.56 to 3.84 fl oz	15.36 fl oz	Allow 5 days between applications.
Warrior II	1.28 to 1.92 fl oz	7.68 fl oz	Allow 5 days between applications.
Thrips, Whiteflies: Thrips damage to small seedlings is uncommon and plants usually recover without treatment. Although whiteflies are common in beans, they are not usually a serious problem.			
Assail 30 SG	4.5 to 5.3 oz	16 oz	Limit 3 applications. Allow 7 days between applications. Not for dried beans.
Blackhawk 36 WG	2.5 to 3.3 oz	20 oz	Allow 5 days between applications. Use an adjuvant. For thrips.

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INSECT CONTROL: Beans[1] *(continued)*

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Brigade 2 EC	2.1 to 6.4 fl oz	12.8 fl oz	Allow 3 days between applications. Dried beans only.
Courier 3.6 SC	9 to 13.6 fl oz	27.2 fl oz	Allow 14 days between applications. For whiteflies on succulent beans only.
Exirel 0.83 SE	13.5 to 20.5 fl oz	61.5 fl oz	Allow 5 days between applications. Use an adjuvant.
Knack 0.83 EC	8 to 10 fl oz	20 fl oz	Allow 14 days between applications. For eggs and immature stages of whiteflies only.
Miteus 0.42 EC	2 pt	4 pt	Allow 14 days between applications. For whiteflies. For snap beans only. 2 applications only.
Movento 2 SC	4 to 5 fl oz	10 fl oz	Allow 7 days between applications. For whiteflies. Requires surfactant.
Orthene 97 S	0.5 to 1 lb	2.12 lb	Allow 3 or 7 days between applications, rate dependent. Not for green beans. For thrips.
Portal 0.4 EC	2 pt	4 pt	Allow 14 days between applications. For whiteflies. For snap beans only. 2 applications only.
Sivanto Prime 1.67 SL	10.5 to 14 fl oz	28 fl oz	Allow 10 days between applications. For whiteflies.

1 Generic products available (Appendix G).

WEED CONTROL: Beans

Product Amt/A	lb A.I./A	Comments
Lima, Snap Beans		
0.5 to 1.6 fl oz Aim 1.9 EW	0.008 to 0.025 carfentrazone	For contact post-emergence control of annual broadleaf weeds and suppression of annual grasses. Can be applied as a preplant, pre-transplant burndown, or before crop emerges to actively growing weeds up to 4 inches tall. Can also be applied post-emergence as a directed hooded application between crop rows. Use min. 10 gal water/A and crop oil 1% v/v. Max. rate 6.1 fl oz/A. PHI = 0 days.
1 to 2 pt Basagran 4S	0.5 to 1 bentazon	Use post-emergence for control of annual broadleaves and suppression of yellow nutsedge. Do not apply until the first trifoliate bean leaf is fully expanded. Some injury may occur but plants will grow out of it. Do not apply more than 4 pt/A per year. PHI = 30 days.
0.4 to 0.67 pt Command 3ME	0.15 to 0.25 clomazone	Use pre-emergence for suppression of annual grasses and broadleaf weeds. Apply once in min. 10 gal water/A. PHI = 45 days.
1.3 to 1.7 pt Dual II Magnum	1.3 to 1.6 s-metolachlor	For control of most annual grasses and certain broadleaves. Apply preplant surface or incorporated or pre-emergence. Small grains may be planted 4½ months following this treatment. See label for other rotational crops.
2 to 4 pt Gramoxone Inteon	0.69 to 1.38 paraquat salt	For non-selective contact kill of annual grasses and broadleaf weeds and top-kill of perennial weeds. **Paraquat product labels require applicators to take an EPA-approved training every 3 years to mix, load, and apply paraquat.**
2.5 to 3 qt Micro-Tech 4 E	2.5 to 3 alachlor	Lima (green) beans only. For control of annual grasses and broadleaf weeds and yellow nutsedge. Max. 1 application/year or 3 qt/A. Apply preplant incorporated within 7 days before planting or surface application before or after planting.
0.5 to 2.5 pt Poast	0.09 to 0.49 sethoxydim	For control of actively growing grasses only. Use high rate on Johnson grass. PHI = 15 days. Max. rate of 2.5 pt/application and 4 pt/season.
1.5 to 3.0 pt Prowl H2O	0.75 to 1.5	Broadcast and incorporate. Not effective on soils with high organic matter
1.5 to 3.0 oz Pursuit	0.023 to 0.047 imazethapyr	See label for specific bean type. Reduced crop growth, quality, and yield, and/or delayed maturity may result from application to edible legume vegetables
0.75 to 1.5 pt Reflex 2 EC	0.18 to 0.36 fomesafen	For post-emergence control of broadleaves and suppression of grasses, apply broadcast to actively growing weeds. Use COC as adjuvant 0.5 to 1% v/v. Max rate is 1.5 pt/A per season. Do not use hay or straw for animal feed or bedding. Check label for plantback restrictions. Timely cultivation 1 to 3 weeks after applying Reflex may assist weed control. PHI = 45 days.
16 to 22 fl oz Roundup WeatherMax	0.69 to 0.94 glyphosate-salt	For non-selective post-emergence control of annual and perennial grasses and broadleaf weeds. Use only AMS 1 to 2% v/v. Adding a non-ionic surfactant can reduce weed control effectiveness. Min. 30 days before planting any non-labeled crop.
0.5 to 1 oz Sandea 75 DF	0.023 to 0.047 halosulfuron	For control of broadleaf weeds and yellow nutsedge. Apply after planting but before cracking in min. 15 gal water/A. PHI = 30 days. Max. 1 oz/A/crop and 2 oz/A per season.
0.5 to 1 oz Sandea DF + 3.5 to 4.5 pt Eptam 7 E	0.023 to 0.047 halosulfuron + 3 to 4 EPTC	For control of broadleaf weeds, grasses, and yellow nutsedge. Apply and incorporate to a depth of ½ to 2 inches just before planting. Max. rate 1 oz Sandea/season and 7 pt Eptam/season. Do not use Eptam on flat-podded beans except Romano.

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WEED CONTROL: Beans *(continued)*

Product Amt/A	lb A.I./A	Comments
9 to 16 fl oz Select Max	0.07 to 0.13 clethodim	For selected post-emergent control of some grasses. For use on succulent shelled beans only. PHI = 21 days. Use a NIS 0.25% v/v for added control. Limit one application per season.
4.0 to 12.0 fl oz Targa	0.026 to 0.0825 quizalofop	Maximum rate 14 oz per season. 7 day interval minimum. PHI = 15 days.
1 to 1.5 pt Treflan HFP 4 E	0.5 to 0.75 trifluralin	For control of annual grasses and broadleaf weeds. Apply and incorporate in spring before planting or in fall in advance of spring planting.
Dry Beans		
5 to 12 fl oz Assure II 0.88L	0.033 to 0.08 quizalofop	For selective post-emergence control of annual grasses and suppression of perennial grasses. Apply to actively growing grasses in 10 to 15 gal water/A. Include 1% v/v crop oil concentrate or 0.25% v/v non-ionic surfactant. Snap beans: 15-day pre-harvest interval and maximum of 14 oz/A per season. Dry beans: 30-day pre-harvest interval and maximum of 28 oz/A per season.
1 to 2 pt Basagran	0.5 to 1 bentazon	Use post-emergence for control of annual broadleaves and suppression of yellow nutsedge. Do not apply until the first trifoliate bean leaf is fully expanded. Some injury may occur but plants will grow out of it. Do not apply more than 4 pt/A per year.
3.5 pt Eptam 7 E	3 EPTC	For control of annual grasses and broadleaf weeds and suppression of yellow nutsedge. Apply before planting and incorporate into soil 2 to 4 inches immediately. Can be applied as a directed lay-by application to soil at the base of the plants before pods start to form. Gives good nutsedge suppression. Do not use on flat podded beans except for Romano beans.
1.2 to 2.0 pt Gramoxone Inteon	0.4 to 0.67 paraquat salt	For non-selective contact kill of annual grasses and broadleaf weeds and top-kill of perennial weeds. Apply as a leaf desiccant in min. 20 gal water/A. Apply when crop is mature or at least 80% pods are yellowing and mostly ripe. Use with non-ionic surfactant 0.25% v/v. Max. 2 applications/season. PHI = 7 days.
14 to 18 fl oz Outlook 6 EC	0.65 to 0.84 dimethenamid-P	For control of annual grasses and broadleaf weeds and suppression of seedling Johnson grass. Can be applied preplant surface or incorporated, pre-emergence or post-emergence to dry beans at 1-3 trifoliate stage. PHI = 70 days.
0.5 to 2.5 pt Poast	0.09 to 0.49 sethoxydim	For control of actively growing grasses only. Use high rate on Johnson grass. PHI = 30 days. Max. rate of 2.5 pt/application and 4 pt/season.
1.5 to 3.0 pt Prowl H2O	0.75 to 1.5 pendimethalin	Broadcast and incorporate. Not effective on soils with high organic matter.
4 fl oz Raptor 1EC	0.031 imazamox	For control of annual grasses and broadleaf weeds. Some varieties are sensitive and injury can occur. Apply post-emergence to actively growing dry beans with at least 1 fully expanded trifoliate leaf. Max. 1 application/season.
0.75 to 1.5 pt Reflex 2 EC	0.18 to 0.36 fomesafen	For post-emergence control of broadleaves and suppression of grasses, apply broadcast to actively growing weeds. Use COC as adjuvant 0.5 to 1% v/v. Max rate is 1.5 pt/A per season. Do not use hay or straw for animal feed or bedding. Check label for plantback restrictions. Timely cultivation 1 to 3 weeks after applying Reflex may assist weed control. PHI = 45 days.
16 to 22 fl oz Roundup WeatherMax 5.5L	0.69 to 0.94 glyphosate-salt	For non-selective post-emergence control of annual and perennial grasses and broadleaf weeds. Use only AMS 1 to 2% v/v. Adding a non-ionic surfactant can reduce weed control effectiveness. Min. 30 days before planting any non-labeled crop.
0.5 to 0.66 oz Permit 75 DF	0.023 to 0.031 halosulfuron	For control of broadleaf weeds and yellow nutsedge. Apply broadcast after planting but before cracking in min. 15 gal water/A. PHI = 30 days. Max. of 0.66 oz/A per crop and 2 oz/A per season.
0.5 to 0.66 oz Permit DF + 3.5 to 4.5 pt Eptam 7 E	0.023 to 0.03 halosulfuron + 3 to 4 EPTC	For control of broadleaf weeds, grasses, and yellow nutsedge. Apply and incorporate to a depth of ½ to 2 inches just before planting. Max. rate 2⁄3 oz Permit/season and 7 pt Eptam/season. Do not use Eptam on flat-podded beans except Romano.
9 to 32 fl oz Select Max	0.07 to 0.24 clethodim	For selected post-emergent control of some grasses. For use on succulent shelled beans only. PHI = 30 days. Use a NIS 0.25% v/v for added control. Limit 64 fl oz per season.
7.5 to 11.5 lb Sonalan 10G	0.75 to 1.15 ethalfluralin	For pre-emergence control of annual grasses and broadleaves. Apply and incorporate before planting.
4.0 to 12.0 fl oz Targa	0.026 to 0.08 quizalofop p-ethyl	For selective control of annual grasses and suppression of perennial grasses. Maximum rate 28 oz per season. 7 day interval minimum. PHI = 30 days.
1 to 2 pt Treflan HFP 4 E	0.5 to 1 trifluralin	For control of annual grasses and broadleaf weeds. Apply and incorporate in spring before planting or in fall in advance of spring planting.

DISEASE CONTROL: Beans

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Anthracnose					
Aproach	11	14	6 to 12 fl oz[5]	24 fl oz	Dry beans only.
Chlorothalonil[4]					There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Bravo Ultrex	M	7	1.25 to 1.8 lb	7.3 lb	
Bravo Weather Stik	M	7	1.375 to 2 pt	8 pt	
Copper, fixed coppers[6]	M				See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Fontelis	7	0	14 to 30 fl oz[5]	72 fl oz	
Headline and pyraclostrobin[4] generics	11	7/30	6 to 9 fl oz[5]	2 apps	See label for PHI. Observe extended PHI.
Priaxor	7/11	7/21	4 to 8 fl oz[5]	2 apps	See label for PHI. Observe extended PHI.
Quilt Xcel and propiconazole + azoxystrobin[4] generics	3/11	7/14	10.5 to 14 fl oz	42 fl oz	See label for PHI.
Quadris and azoxystrobin[4] generics	11	0/14	6 to 15.5 lb	90 fl oz	See label for PHI.
Quadris Opti	11/M	14	1.6 to 2.4 pt		Dry beans only.
Quilt Xcel and propiconazole + azoxystrobin[4] generics	11/3	7/14	10.5 to 14 fl oz	42 fl oz	See label for PHI.
Topsin M and thiophanate-methyl[4] generics	1	14/28	1 to 2 lb	5 app	See label for PHI. May cause leaf crinkling or increased greening of leaves. There are multiple Topsin formulations and thiophanate methyl generics. See label for rates.
Bacterial Blights (i.e. Halo Blight, Common Blight, Brown Spot)					
Copper, fixed coppers[6]	M				See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Gray Mold, White Mold					
Botran 75 W	14	2	2.25 to 4 lb	n/a	Snap beans only for control of white mold. Use low rate for bush varieties, high rate for pole varieties.
Botran 5F	14	2	1.3 to 1.6 qt	5.2 qt	
Cannonball WP and fludioxonil[4] generics	12	7	7 oz	28 oz	For white mold, make first application at 10-20% bloom.
Chlorothalonil[4]					Snap beans only. PHI is 7 days.
Bravo Ultrex	M	7	2.7 lb	10.9 lb	
Bravo WeatherStik	M	7	3 pt	12 pt	There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Cueva	M	0	0.5 to 2 gal	n/a	OMRI-listed. Mix in 100 gallons of water, use 50 to 100 gal/A of solution. Apply before 25% bloom for white mold.
Endura and boscalid[4] generics	7	7/21	8 to 11 oz	2 apps	PHI is 7 days for snap (succulent) beans, 21 days for dry beans.
Fontelis	7	0	14 to 30 fl oz[5]	72 fl oz	
Rovral and iprodione[4] generics	2	0	1.5 to 2 pt	2 apps	Apply no later than full bloom.
Kenja 400SC	7	7/30	17 oz	2 apps	
Omega 500F	29	30	0.5 to 0.85 pt	1.75 pt	
Priaxor	7/11	7/21	6 to 8 fl oz[5]	2 apps	
Proline 480 SC	3	7	4.3 to 5.7 fl oz	3 apps	Dry beans only for control of white mold.

(continued on next page)

DISEASE CONTROL: Beans *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Quadris and azoxystrobin[4] generics	11	0/14	6 to 15.5 lb	90 fl oz	See label for PHI.
Quash	3	21	4 fl oz	8 fl oz	Dry beans only, for white mold management.
Switch 62.5WG	9/12	7	11 to 14 oz	56 oz	
Topsin M and thiophanate-methyl[4] generics	1	14/28	1 to 2 lb	5 app	See label for PHI. May cause leaf crinkling or increased greening of leaves. There are multiple Topsin formulations and thiophanate methyl generics. See label for rates.
Vertisan	7	21	14 to 20 fl oz[5]	41 fl oz	Observe pre harvest interval.
Rhizoctonia Web Blight, Pod Rot					
Quadris and azoxystrobin[4] generics	11	0/14	0.4 to 0.8 fl oz/ 1000 row ft	90 fl oz	Pre- and post-harvest planting in furrow or as banded application.
Quadris Opti	11/M	14	1.6 to 2.4 pt		Dry beans.
Quilt Xcel and propiconazole + azoxystrobin[4] generics	3/11	7/14	10.5 to 14 fl oz	42 fl oz	See label for PHI.
Rally and myclobutanil[4] generics	3	0	4 to 5 oz	1.25 lb	Snap beans only, Rhizoctonia pod rot. Apply as pods begin to develop; continue every 7 to 10 days.
Tilt, and propiconazole[4] generics	3	7	4 fl oz	12 fl oz	May cause leaf crinkling or increased greening of leaves.
Vertisan	7	21	14 to 20 fl oz[5]	41 fl oz	Observe pre harvest interval.
Rust					
Aproach	11	14	6 to 12 fl oz[5]	24 fl oz	Dry beans only.
Chlorothalonil[4]					May be used on snap or dry beans for rust.
Bravo Ultrex	M	7	1.25 to 1.8 lb	4 apps	
Bravo WeatherStik	M	7	1.375 to 2 pt	8 pt	There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Fontelis	7	0	14 to 30 fl oz[5]	72 fl oz	
Headline and pyraclostrobin[4] generics	11	7/30	6 to 9 fl oz[5]	2 apps	See label for PHI. Observe extended PHI.
Toledo, and tebuconazole[4] generics	3	7/14	4 to 6 fl oz	12 to 24 fl oz	See label for rates for fresh and dry beans.
Luna Experience	7/3	14	8 to 12.8 fl oz	25.6 fl oz	
Priaxor	7/11	7/21	4 to 8 fl oz[5]	2 apps	
Proline 480 SC	3	7	5.7 fl oz	3 apps	Dry beans only.
Quadris and azoxystrobin[4] generics	11	0/14	6 to 15.5 lb	90 fl oz	See label for PHI.
Quadris Opti	11/M	14	1.6 to 2.4 pt		Dry beans.
Quadris Top	11/3	14	12 to 14 fl oz		
Quilt Xcel and propiconazole + azoxystrobin[4] generics	3/11	7/14	10.5 to 14 fl oz	42 fl oz	14 day PHI for dry beans.
Rally and myclobutanil[4] generics	3	0	4 to 5 oz	1.25 lb	Snap beans only.
Sulfur[4]	M	0			Rust. Phytotoxicity may occur if applications are made when temperatures exceed 90°F.
Vertisan	7	21	14 to 20 fl oz[5]	41 fl oz	Apply before disease onset. Observe pre harvest interval.

(continued on next page)

DISEASE CONTROL: Beans *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Pythium Damping-off, Seedling Diseases, Root Rot, Cottony Leak					
MetaStar and metalaxyl[4] generics	4	0	2 to 4 pt	1 app	Apply pre- or post-planting. See label for application detail. Metastar can be tank-mixed with Terraclor to provide additional protection against *Rhizoctonia*.
Ranman	21	0	2.75 fl oz	16.5 fl oz	Cottony leak. Also Phytophthora blight, downy mildew.
Reason	11	3	5.5 to 8.2 fl oz	24.6 fl oz	Cottony leak only.
Ridomil Gold and mefenoxam[4] generics	4	0	0.5 to 1 pt	1 pt	Apply pre- or post-planting. See label for application detail.
Ridomil Gold PC GR	4/M	0	12 oz[3]	1 app	For preplant application only. Adjust equipment so that granules are mixed with soil before covering seed. Also provides control of *Rhizoctonia*.
Rhizoctonia Damping-off, Seedling Diseases, Stem/Root Rot					
Blocker 4F/10G	14	45	2.2 to 3.3 fl oz[3]	1 app	Use as an In-furrow spray at planting. Actual rate is dependent on row spacing; see label for directions.
Headline, and pyraclostrobin[4] generics	11	7/30	0.1 to 0.8 fl oz[3]	1 app	Use as an In-furrow spray at planting; see label for directions.
Quadris and azoxystrobin[4] generics	11	0/14	0.4 to 0.8 fl oz/ 1000 row ft	90 fl oz	Pre- and post-harvest planting in furrow or as banded application.
Quilt Xcel and propiconazole + azoxystrobin[4] generics	3/11	7/14	10.5 to 14 fl oz	42 fl oz	See label for PHI.

1 Products with numerical FRAC codes must be alternated or tank-mixed with products that have a different FRAC code to discourage resistance development. See product label for maximum number of consecutive applications allowed. Refer to the table on pages 22-24 for more information on FRAC codes.
2 Pre-harvest interval.
3 Per 1,000 row-feet.
4 Generic products available (Appendix F). Amounts and seasonal limits per acre are product dependent.
5 Use higher rate when pressure is severe.
6 Fixed coppers labeled in KY include: Badge SC, Badge X2, Basic Copper 53, Champ, Champ WG, ChampION++, C-O-C-S WDG, Cueva, Cuprofix, Cuproxat, Kentan, Kocide 2000, Kocide 3000, Kocide DF, KOP-5, MasterCop, Nordox 75 WG, Nu-Cop 30 HB, Nu-Cop 50DF, Phyton 27, Phyton 35, and Previsto. Rates may vary by product and by crop. Refer to specific product label for this information.

Cole Crops

Mustard family (Brassicaceae): *Brassica* (broccoli, Brussels sprouts, cabbage, cauliflower, Chinese cabbage, kohlrabi)

Planting and Culture

The ground for spring cole crops should be plowed in the fall in order to have crops ready for the early market. Cabbage should be transplanted to the field by mid-March in most parts of Kentucky; broccoli and Brussels sprouts should be in the field by the middle of April for the spring crop (see Appendix K). Avoid poorly drained fields. A good firm seedbed should be prepared by disking. Cole crops do well on ground that has been in tobacco. Fescue sod ground is also good if plowed early in the fall and allowed to decompose.

Cauliflower does not do well as a spring crop in Kentucky. Cabbage, broccoli, and cauliflower all do well as fall crops. Cabbage and cauliflower should be transplanted by early August at the latest, whereas broccoli can be transplanted as late as mid-August. Growers may want to select shorter maturing varieties for late summer plantings. Be aware that days-to-maturity for most cole crops is based on days from transplant. Cauliflower does well when transplanted around July 15 to 20 for a fall crop. Irrigation is often critical for establishing the fall crop.

Use transplants for early market. Sort plants by size to have uniformity in the field. This is helpful at harvest time. A tobacco setter can be used to transplant. Space cabbage plants 12 to 14 inches in the row with rows spaced 36 inches apart. A plant population of 14,000 plants per acre is desirable. Brussels sprouts and cauliflower should be spaced 18 to 20 inches apart in the row with rows 36 inches apart. Broccoli should be spaced 12 to 14 inches apart to keep heads from becoming too large. A 10-inch spacing and double rows 20 inches apart are used for smaller, bunching-size broccoli heads.

A starter fertilizer dissolved in water and applied around the root system during transplanting is recommended. Use 3 pounds of starter in 50 gallons of water, and apply half a pint per plant. Some insecticides can be added to starter solution to control soil insects (see "Insect Control" table).

Fertilizing

Get a soil test and follow the recommendations. Lime should be applied if needed to bring the pH to around 6.5. Cole crops are heavy users of sulfur; soils prone to deficiencies can be amended by using one of the many sulfur-containing fertilizers to supply 10 to 20 pounds actual sulfur per acre. Boron deficiencies have appeared in cabbage in several Kentucky counties. The addition of 2 pounds per acre of actual boron is recommended where cabbage is to be planted (see Appendix B).

Cold Tolerance, Harvesting, and Storage

The cold tolerance of cole crops varies somewhat with the weather conditions preceding the cold period. These minimum temperatures are usually tolerated by cole crops in the fall:

Broccoli*	22-23°F
Brussels Sprouts	20°F
Cabbage	17-18°F
Cauliflower	22-24°F

**Certain varieties may be damaged at 25°F.*

Broccoli heads should be cut before any yellow petals show. Cut the heads with 6 to 8 inches of the stem attached. Later maturing lateral stalks should be cut in a similar manner. Broccoli is sold to the wholesale fresh market in cartons holding 14 bunches with two to three heads to the bunch.

Brussels sprouts should be harvested when they are 1 to 1 ¼ inches in diameter. The lower leaves of the plant should first be broken away and the sprouts cut off close to the stem with a sharp knife.

Fresh market cabbage should be cut when heads are firm. Cut 2 ½- to 3 ½-pound heads low enough to leave two to three loose wrapper leaves. Cabbage is usually marketed in 50-pound boxes or bags with 16 to 18 heads per bag. Allow 3 to 4 extra pounds for shrinkage. For the slaw market cabbage, cut 4- to 8-pound heads, remove wrapper leaves, and put in 20-bushel bins.

Cauliflower should have the leaves pulled around the developing curd when the curd is about the size of a quarter. The head will then be ready to harvest in about a week to 10 days. When tying the curds, use rubber bands of different colors to represent different tying dates. Tie high enough so there is adequate air circulation around the heads, which will help reduce "riciness" and molding of the head. Tying the leaves up around the developing curd results in a white head. Heads should be cut before they become "ricy" in appearance. High temperatures may cause riciness to the head, with very poor quality.

Cauliflower is packed in cartons containing nine to 12 firmly wrapped heads. Store cole crops at 32°F and 90 to 95 percent relative humidity.

VARIETIES: Pak Choi, Chinese Cabbage, Kohlrabi

	DTM[4]	Comments
Pak Choi[1]		
Joi Choi (hybrid)	47	Slow bolting, very uniform.
Chinese Cabbage[2]		
Blues	57	Excellent for spring or fall, tolerant to virus, downy mildew, white spot, Alternaria leaf spot and bacterial soft rot—Napa type.
Yuki	62	Early slow bolting similar to China Express—Napa type.
Jade Pagoda (hybrid)	65	Excellent for spring crop—Michili type. Slow bolting.
Kohlrabi[3]		
Winner (hybrid)	45	Early maturing; slow to lose fine texture.
Kossak	80	Large, excellent taste, no fiber development, stores well.
Kolibri	45	Excellent purple color and taste

1 B. rapa, Chinensis group
2 B. rapa, Pekinensis group
3 B. oleracea, Gongylodes group
4 Days to maturity from seeding.

VARIETIES: Cabbage[1]

	DTM[2]	Head Size (lb)	Yellows Resistant	Black Rot Tolerant	Tipburn Tolerant
Green					
Artost	68	4	X		
Blue Vantage	72	4	X	X	X
Atlantis	72	4	X	X	
Blue Dynasty	75	4	X	X	X
Bronco	78	4	X	x	X
Cecile	80	3.5	X	X	X
Ramada	83	4	X	X	X
Cheers	85	5	X	X	
Storage No. 4	95	4-8	X		
Red					
Red Globe (Scarlet King)	70	4			
Red Dynasty	72	3.5-5		x	
Rio Grande Red	73	4.5			
Rondale	75	4	X		X
Super Red 80	83	3.5			X
Savoy					
Savoy Ace Improved	73	3.5	X		
Savoy King	80	4.5			X

1 Capitata group (all are hybrids)
2 Days to maturity when transplanted

VARIETIES: Broccoli, Brussels Sprouts, Cauliflower

Note: see "Greens" chapter for broccoli raab varieties.

Variety *(all are hybrids)*	DTM[4]	Comments
BROCCOLI[1]		
Packman	48	Early, production, good for spring and early fall.
Eastern Crown	55-81	Compact heads, small bead size
Emerald Crown	55-81	Uniformly green heads, small bead size
Green Magic	60	Large, blue-green heads; downy mildew tolerant.
Millennium	60-85	Compact uniformly green heads, small bead size, high yielding
Emerald Star	63-85	Compact heads, high yielding
Premium Crop	65	Medium head, tight bead, for farmers market sales.
Arcadia	70	Spring or fall crop; large, blue-green tight-beaded heads; downy mildew tolerant.
Marathon	75	Large blue-green heads; excellent for bunching or crown cuts; downy mildew tolerant; very cold tolerant, good for early spring production.
BRUSSELS SPROUTS[2]		
Jade Cross, E Strain	85	Top recommendation for KY; plants grow to about 2 feet tall; medium-sized closely-spaced sprouts, low bacterial leaf spot incidence.
Dimitri	105	Plant topping not needed, 1-1.5 inch round sprouts, long stems with widely-spaced sprouts, low bacterial leaf spot incidence; harvest when leaves begin to break off.
CAULIFLOWER[3]		
Snow Crown	55	Early maturing; very uniform head development; Up to 8 inch diameter heads.
Steady	67	Early maturing, domed heads, self-wrapping tendencies.
Freedom	67	Heat tolerant, wrapper leaves, self-blanching
Aquarius	70	Fall crop, heat tolerant, dense smooth firm round heads, good curd cover.
Argos	70	Round very white heads, good curd quality, concentrated harvest, medium heat tolerance, good leaf cover for self-blanching, but still requires tying.
Flamenco	71	Fancy dense heads, widely adapted, for fall production, good wrapper leaves.
White Sails	75	Excellent fall crop, attractive.
Synergy	75	Fall crop, globe shaped heads, dense firm white curds, good leaf cover.
Casper	76	Self-blanching, nice white curd color, very low level of head riciness or fuzziness
Graffiti	74	Purple heads, used fresh, will turn a deep green when cooked.

1 Italica group
2 Gemmifera group
3 Botrytis group
4 Days to maturity when transplanted.

FERTILIZER: Cole Crops

Soil Test Results (lb/A)		Fertilizer Needed (lb/A)
Phosphorus		**Phosphate (P_2O_5)**
Low	<31	121-180
Medium	31-60	61-120
High	61-80	31-60
Very High	>80	0-30
Potassium		**Potash (K_2O)**
Low	<201	101-150
Medium	201-300	51-100
High	301-450	1-50
Very High	>450	0
Nitrogen		**N**

Broadcast and plow under 50 lb N/A. Sidedress with 50 lb N/A when heads begin forming. A second sidedressing of 50 lb of N/A two weeks later should also be applied. Alternatively begin fertigating when heads begin forming with 10 to 15 lb of nitrogen per acre weekly using a total of 100 lb of nitrogen per acre. Delaying N application may cause cabbage heads to burst. Too high levels of N may result in greater internal tipburn of cabbage. Calcium nitrate should be used where tipburn has been a problem. High nitrogen levels cause hollow stem in broccoli. Usually 100 lb total nitrogen is sufficient for broccoli.

PESTICIDE SAFETY: Cole Crops

	Signal[1]	Re-entry (hrs)	Harvest (days)
INSECTICIDES			
Actara 25 WP	C	12	0
Admire Pro	C	12	7/21[5]
Assail 30 SG	C	12	7
Avaunt eVo 30 DG	C	12	3
Belay 2.13 SC	C	12	7/21[5]
Beleaf 50 SG	C	12	0
Bt products	C	12	0
Coragen 1.67 SC	-	4	3
Courier 40 SC	W	12	1
Dimethoate 4 E	W	48	7
Exirel 0.83 SE	C	4	1
Fulfill 50 WDG	C	12	7
Harvanta 50 SL	C	4	1
Intrepid 2 F	C	4	1
Malathion 8	C	12	3/7[5]
Movento 2 SC	C	24	1
Oberon 2 SC	C	12	7
Platinum 2 SC	C	12	30
PQZ 1.87 SC	C	12	1
Radiant SC	C	4	1
Requiem 25 EC	C	4	0
Rimon 0.83 EC	W	12	7
Scorpion 3.5 SL	C	12	1/21[5]
Sevin XLR Plus	W	12	3/14[5]
Sivanto Prime 1.67 SC	C	4	1/21[5]
Torac 1.29 EC	W	12	1
Venom 70 SG	C	12	1/21[5]
Verimark 1.67 SC	-	4	AP[2]
Versys 0.83 EC	C	12	0
Restricted Use			
Asana XL	W	12	3
Baythroid XL	W	12	0

(continued)

PESTICIDE SAFETY: Cole Crops *(continued)*

	Signal[1]	Re-entry (hrs)	Harvest (days)
Brigade 2 EC	W	12	7
Capture LFR	W	12	AP[2]
Danitol 2.4 EC	W	24	7
Diazinon AG500	C	24	7/10/21[5]
Diazinon 50 W	C	24	7/10/21[5]
Fastac 0.83 EC	D	12	1
Lannate 90 SP	DP	48	1/3/10[5]
Mustang Maxx	W	12	1
Permethrin 3.2 EC	C	12	1
Proaxis 0.5 EC	C	24	1
Proclaim 5 WDG	C	48	7
Warrior II	W	24	1
FUNGICIDES[3]			
Actigard 50 WG	C	12	7
Azoxystrobin[4]	C	4	0
Blocker 10G/4F	C	12	0
Cabrio EG	C	12	0
Chlorothalonil[4]	D	48	7
Dexter Max	C	24	7
Emblem	C	12	7
Endura	W	12	0
Fixed coppers[4]	D	24/48	0
Flint Extra	C	12	0
Fluazinam[4]	W	12	7/50[5]
Fontelis	C	12	0
Forum SC	C	12	7
Inspire Super	C	12	7
Iprodione[4]	W	12	0
Luna Sensation	C	12	0
Mancozeb[4]	C	24	7
ManKocide	D	48	7
Mefenoxam[4]	W	48	0/7[5]
Metalaxyl[4]	W	48	0
Orondis Ultra A	C	4	0
Orondis Ultra B	C	4	0
Priaxor	C	12	3
Presidio	C	12	2
Procure 480 SC	C	12	1
Quadris	C	4	0
Quadris Top	C	12	1
Ranman	C	12	0
Reason 500 SC	C	12	2
Revus	C	4	1
Rhyme	W	12	7
Sulfur[4]	C	24	0
Switch 62.5 WG	C	12	7
Topguard	C	12	7
Trionic	C	12	1
Terraclor	W	12	0
Zampro	C	12	0

1 W: Warning, C: Caution, D: Danger; P: Poison
2 AP: At planting.
3 None of these fungicides is labeled on all Cole crops, so check labels carefully.
4 Several formulations are marketed. See the general introduction for more details on fungicides.
5 PHI depends on crop type and application method.

INSECT CONTROL: Cole Crops[1,2,3]

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
To prevent or reduce insect problems, destroy crop remnants immediately after harvest. When growing both spring and fall cole crops, allow for a 2- to 3-week period during midsummer without a cole crop. Always use a spreader/sticker to increase coverage on cole crops.			
PREPLANT INCORPORATED			
Cutworms, Root Maggots: Eliminate weeds from field margins and plow fields at least 2 weeks before planting to destroy cutworm food sources and egg laying sites.			
Capture LFR	3.4 to 6.8 fl oz	1 application	Apply as a band over the furrow or in-furrow.
Diazinon 50 W	4 to 6 lb	1 application	Incorporate immediately in top 3-4 inches of soil.
TRANSPLANT WATER OR DRENCH APPLICATION			
Root Maggots			
Diazinon AG 500	0.25 to 0.5 pt/50 gal	1 application	Use 200 to 300 gals of water per acre.
SOIL APPLICATION			
Aphids: Do not use a foliar spray of Actara, Belay, Venom, Provado, or Assail following a soil application of Admire, Belay, Platinum, or Venom.			
Admire Pro	4.4 to 10.5 fl oz	10.5 fl oz	Use as a 2 inch band during bedding, an in-furrow spray, a post-seeding drench, or a sidedress after plants are established.
Belay 2.13 SC	9 to 12 fl oz	12 fl oz	Limit one application.
Platinum 2 SC	5 to 11 fl oz	11 fl oz	See label for soil application methods.
Sivanto Prime 1.67SC	21 to 28 fl oz	28 fl oz	
Vemon 70 SG	5 to 7.5 oz	12 fl oz	-
Verimark 1.67 SC	6.75 to 13.5 fl oz	61.5 fl oz	Aids in caterpillar control.
FOLIAR TREATMENTS			
Aphids, Harlequin Bugs, Stink Bugs, Flea Beetles			
Actara 25 W	1.5 to 3 oz	11 oz	Allow 7 days between applications.
Admire Pro	1.3 fl oz	6.5 fl oz	Allow 5 days between applications. For aphids and flea beetles.
Assail 30 SG	2 to 4 oz	20 oz	Limit 5 applications. Allow 7 days between applications.
Belay 2.13 SC	3 to 4 fl oz	12 fl oz	Allow 10 days between applications.
Beleaf 50 SG	2 to 2.8 oz	8.4 oz	Allow 7 days between applications. For aphids only.
Brigade 2 EC	2.1 to 6.4 fl oz	32 fl oz	Allow 7 days between applications.
Danitol 2.4 EC	10.67 to 16 fl oz	42.6 fl oz	Allow 7 days between applications.
Dimethoate 4 E	0.5 to 1 pt	3 pt	Aphids only. Not for use on Chinese cabbage or Brussels sprouts.
Exirel 0.83 SE	13.5 to 20.5 fl oz	61.5 fl oz	Allow 5 days between applications. For aphids and flea beetles only.
Fastac 0.83 EC	2.2 to 3.8 fl oz	11.4 fl oz	Allow 7 days between applications. For flea beetles and harlequin bug.
Fulfill 50 WDG	2.75 oz	5.5 oz	Aphids only. Allow 7 days between applications.
Malathion 8	1.25 pt	2 applications	Aphids and flea beetles only. Allow 7 days between applications.
Movento 2 SC	4 to 5 fl oz	10 fl oz	Allow 7 days between applications. For aphids only. Requires surfactant.
Mustang Maxx	3.2 to 4 fl oz	24 fl oz	Allow 7 days between applications.
PQZ 1.87 SC	2.4 to 3.2 fl oz	4.8 fl oz	Limit 2 applications. Allow 7 days between applications.
Scorpion 35 SL	2 to 7 fl oz	10.5 fl oz	Allow 7 days between applications.
Sevin XLR Plus	0.5 to 2 qt	6 qt	Not for aphids. Allow 7 days between applications. Use within 30 days of transplanting.
Sivanto Prime 1.67SC	7 to 14 fl oz	28 fl oz	Allow 7 days between applications.
Torac 1.29 EC	17 to 21 fl oz	42 fl oz	Allow 14 days between applications. Limit 2 applications. Aphids and flea beetles only.
Venom 70 SG	1 to 4 oz	6 oz	Allow 7 days between sprays. Flea beetle only.
Versys 0.83 EC	1.5 fl oz	14 fl oz	Allow 7 days between applications.
Warrior II	1.28 to 1.92 fl oz	15.36 fl oz	Stink bugs and flea beetles only.

(continued on next page)

INSECT CONTROL: Cole Crops[1,2,3] *(continued)*

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Beet Armyworms: These are infrequent but serious pests of cole crops in Kentucky.			
Avaunt eVo 30 DG	3.5 oz	14 oz	Allow 3 days between applications.
Coragen 1.67 SC	3.5 to 7.5 fl oz	15.4 fl oz	Soil or foliar, see label for limitations. Allow 3 days between applications.
Exirel 0.83 SE	7 to 13.5 fl oz	61.5 fl oz	Allow 5 days between applications.
Harvanta 50 SL	10.9 to 16.4 fl oz	49.2 fl oz	Allow 7 days between applications.
Intrepid 2 F	4 to 10 fl oz	64 fl oz	-
Proclaim 5 WDG	2.4 to 4.8 oz	19.2 oz	Allow 7 days between applications.
Rimon 0.83 EC	6 to 12 fl oz	24 fl oz	Target small larvae.
Cabbage Loopers, Yellowstriped Armyworm: Treat when 20% of the plants are infested with looper larvae during the cotyledon stage, when 15% of the plants are infested up to the cupping stage, and when 5% of the plants are infested from cupping until harvest.			
Asana XL	5.8 to 9.6 fl oz	76.8 fl oz	Not for use on Brussels sprouts.
Avaunt eVo 30 DG	2.5 to 3.5 oz	14 oz	Allow 3 days between applications.
Baythroid XL	1.6 to 2.4 fl oz	12.8 fl oz	Limit 3.2 fl oz per 7-day period.
Brigade 2 EC	2.1 to 6.4 fl oz	32 fl oz	Allow 7 days between applications.
Bt products	See labels	-	-
Coragen 1.67 SC	3.5 to 7.5 fl oz	15.4 fl oz	Soil or foliar, see label for limitations. Allow 3 days between applications.
Danitol 2.4 EC	10.67 to 16 fl oz	42.6 fl oz	Allow 7 days between applications.
Fastac 0.83 EC	3.2 to 3.8 fl oz	11.4 fl oz	Allow 7 days between applications.
Exirel 0.83 SE	10 to 17 fl oz	61.5 fl oz	Allow 5 days between applications.
Intrepid 2 F	4 to 10 fl oz	64 fl oz	-
Malathion 8	1.25 pt	2 applications	Allow 7 days between applications.
Mustang Maxx	3.2 to 4 fl oz	24 fl oz	Allow 7 days between applications.
Permethrin 3.2 EC	2 to 4 fl oz	16 fl oz	For broccoli, cauliflower, Brussels sprouts, and Chinese broccoli.
	2 to 8 fl oz	16 fl oz	For cabbage and Chinese cabbage only.
Proaxis 0.5 EC	1.92 to 3.2 fl oz	30.72 fl oz	-
Proclaim 5 WDG	3.2 to 4.8 oz	19.2 oz	Allow 7 days between applications.
Radiant SC	5 to 10 fl oz	34 fl oz	Allow 4 days between applications.
Rimon 0.83 EC	6 to 12 fl oz	24 fl oz	Target small larvae.
Warrior II	0.96 to 1.6 fl oz	15.36 fl oz	-
Cross-Striped Cabbageworms, Imported Cabbageworms: Treat when 20% of the plants are infested with any of these larvae during the cotyledon stage, when 15% of the plants are infested up to the cupping stage, and when 5% of the plants are infested from cupping until harvest.			
Avaunt eVo 30 DG	2.5 to 3.5 oz	14 oz	Allow 3 days between applications.
Baythroid XL	1.6 to 2.4 fl oz	12.8 fl oz	Limit 3.2 fl oz per 7-day period.
Brigade 2 EC	2.1 to 6.4 fl oz	32 fl oz	Allow 7 days between applications.
Bt products	See labels	-	-
Coragen 1.67 SC	3.5 to 7.5 fl oz	15.4 fl oz	Soil or foliar, see label for limitations. Allow 3 days between applications.
Danitol 2.4 EC	10.67 to 16 fl oz	42.6 fl oz	Allow 7 days between applications.
Fastac 0.83 EC	2.2 to 3.8 fl oz	11.4 fl oz	Allow 7 days between applications.
Exirel 0.83 SE	7 to 13.5 fl oz	61.5 fl oz	Allow 5 days between applications.
Intrepid 2 F	4 to 10 fl oz	64 fl oz	-
Malathion 8	1.25 pt	2 applications	Allow 7 days between applications.
Mustang Maxx	2.24 to 4 fl oz	24 fl oz	Allow 7 days between applications.
Permethrin 3.2 EC	2 to 4 fl oz	16 fl oz	For broccoli, cauliflower, Brussels sprouts, and Chinese broccoli.
	2 to 8 fl oz	16 fl oz	For cabbage and Chinese cabbage only.
Proaxis 0.5 EC	1.92 to 3.2 fl oz	30.72 fl oz	-
Proclaim 5 WDG	2.4 to 4.8 oz	19.2 oz	Allow 7 days between applications.
Radiant SC	5 to 10 fl oz	34 fl oz	Allow 4 days between applications.
Rimon 0.83 EC	6 to 12 fl oz	24 fl oz	Target small larvae.
Sevin XLR Plus	1 to 2 qt	6 qt	Allow 7 days between applications. Use within 30 days of transplanting.
Warrior II	0.96 to 1.6 fl oz	15.36 fl oz	-

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INSECT CONTROL: Cole Crops[1,2,3] *(continued)*

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Cutworms: Eliminate weeds from field margins and plow fields at least 2 weeks before planting to destroy cutworm food sources and egg laying sites.			
Asana XL	5.8 to 9.6 fl oz	76.8 fl oz	Not for use on Brussels sprouts.
Baythroid XL	0.8 to 1.6 fl oz	12.8 fl oz	Limit 3.2 fl oz per 7-day period.
Fastac 0.83 EC	2.2 to 3.8 fl oz	11.4 fl oz	Allow 7 days between applications.
Mustang Maxx	2.24 to 4 fl oz	24 fl oz	Allow 7 days between applications.
Proaxis 0.5 EC	1.92 to 3.2 fl oz	30.72 fl oz	-
Warrior II	0.96 to 1.6 fl oz	15.36 fl oz	-
Diamondback Moth Larvae: Diamondback moth larvae are able to rapidly develop resistance to most major classes of insecticides. Do not tank-mix insecticides with the same mode of action and frequently rotate among insecticides with different modes of action to discourage resistance. Treat when 20% of the plants are infested with diamondback larvae during the cotyledon stage, when 15% of the plants are infested up to the cupping stage, and when 5% of the plants are infested from cupping until harvest. IRAC Codes: Insecticides followed by the same number share the same mode of action.			
Avaunt eVo 30 DG (22)	3.5 oz	14 oz	Allow 3 days between applications.
Bt products (11B2)	See labels	-	-
Coragen 1.67 SC (28)	3.5 to 7.5 fl oz	15.4 fl oz	Soil or foliar, see label for limitations. Allow 3 days between applications.
Exirel 0.83 SE	7 to 13.5 fl oz	61.5 fl oz	Allow 5 days between applications.
Harvanta 50 SL (28)	10.9 to 16.4 fl oz	49.2 fl oz	Allow 7 days between applications.
Proaxis 0.5 EC (3)	2.56 to 3.84 fl oz	30.72 fl oz	-
Proclaim 5 WDG (6)	2.4 to 4.8 oz	19.2 oz	Allow 7 days between applications.
Radiant SC (5)	5 to 10 fl oz	34 fl oz	Allow 4 days between applications.
Rimon 0.83 EC (15)	6 to 12 fl oz	24 fl oz	Target small larvae.
Sevin XLR Plus (1A)	1 to 2 qt	6 qt	Allow 7 days between applications. Use within 30 days of transplanting.
Torac 1.29 EC (21A)	17 to 21 fl oz	42 fl oz	Allow 14 days between applications. Limit 2 applications.
Root Maggots			
Diazinon 50 W	1 to 1.5 lb per 200 to 300 gal water	-	Direct spray at base of plants. May result in stand reduction due to stress at transplanting.

1 See Kentucky Cabbage Insect Pest Management Scout Manual (IPM-11) for additional information on cabbage pests and their control.
2 See An IPM Scouting Guide for Common Problems of Cole Crops in Kentucky (ID-216) for photos of pests.
3 Generic products available (Appendix G).

WEED CONTROL: Cole Crops

Product Amt/A	lb A.I./A	Comments
1.0 to 2.0 fl oz Aim 2 EC	0.008 to 0.025 carfentrazone	Apply no later than one day before transplanting, or seven days before seeding. See label for rate for crop oil or nonionic surfactant. Coverage is essential for good weed control. See label for more information.
0.67 to 1.3 pt Command 3ME	0.25 to 0.5 clomazone	Cabbage only—not labeled on Chinese vegetables. Apply before transplanting and incorporate to a depth of 1 inch. Use a min. 10 gal water/A. Do not replant treated field with any crops inconsistent with rotational guidelines. PHI = 45 days.
6 to 10 lb Dacthal W-75	4.5 to 7.5 DCPA	For pre-emergence control of annual grasses and broadleaves. Apply at seeding or transplanting. Can be broadcast over transplants. Can be preplant incorporated.
2 to 4 lb Devrinol 50 DF	1 to 2 napropamide	Not labeled on Chinese vegetables. For control of annual grasses and broadleaf weeds. Apply to weed-free soil and incorporate 1 inch before seeding or transplanting or irrigate within 24 hours of application to soak soil to a depth of 2 to 4 inches. Do not plant rotational crops that are not specified on the label until 12 months after last Devrinol application. Most effective in combination with Goal.
0.5 to 1.3 pt Dual Magnum	0.48 to 1.27 s-metolachlor	See the "Dual Magnum 24(c) Label" section on page 15.

(continued on next page)

WEED CONTROL: Cole Crops *(continued)*

Product Amt/A	lb A.I./A	Comments
1 to 2 pt Goal 2XL	0.25 to 0.5 oxyfluorfen	For pre-emergence and post-emergence control of certain annual grasses and most broadleaves. Apply to soil after final tillage but before transplanting. Do not use on direct seeded cole crops. If plants contact treated soil, some foliar burn may occur but plants generally outgrow symptoms. Do not use post-transplant. Do not use on Brussels sprouts. Max. rate is 2 pt/A.
2.0 to 4.0 pt Gramoxone Inteon	0.69 to 1.38 paraquat salt	For non-selective contact kill of annual grasses and broadleaf weeds and top-kill of perennial weeds. Apply preplant, pre-emergence, or before transplanting in min. 10 gal water/A. Apply banded or broadcast. Use higher rate for heavy weed infestations. Use non-ionic surfactant 0.25% v/v. **Paraquat product labels require applicators to take an EPA-approved training every 3 years to mix, load, and apply paraquat.**
5 to 6 qt Prefar 4 E	5 to 6 bensulide	For control of grasses and broadleaf weeds. Apply preplant and incorporate to 1 to 2 inch depth. Apply pre-emergence only if it can be watered in within 36 hours. Max. rate of 6 qt/season.
0.5 to 1.5 pt Poast	0.09 to 0.28 sethoxydim	For control of actively growing grasses only. Rate for Chinese Brassica vegetables is 0.5 to 1.5 pt. Use higher rate on Johnson grass. PHI = 30 days. Max. rate of 1.5 pt/application and 3 pt/season.
16 to 22 fl oz Roundup WeatherMax 5.5L	0.69 to 0.94 glyphosate-salt	For non-selective post-emergence control of annual and perennial grasses and broadleaf weeds. Use only AMS 1 to 2% v/v. Adding a non-ionic surfactant can reduce weed control effectiveness. Min. 30 days before planting any non-labeled crop.
9 to 16 fl oz Select Max	0.07 to 0.12 clethodim	For selective post-emergence of actively growing annual grasses and suppression of perennial grasses. Add crop oil 1% v/v. Max. 16 fl oz/application. Min. 14 days between applications. PHI = 30 days.
3 to 12 fl oz Spartan 4F	0.09 to 0.38 sulfentrazone	Processing and transplanted cabbage only. Apply 60 days prior to transplanting and allow rain to move into soil for early preplant application. For preplant incorporation apply as a broadcast and incorporate to depths no greater than 2 inches. May be applied in row middles only of transplanted cabbage up to 72 hours after transplant.
0.25 to 0.5 pt Stinger	.09 to 0.187 clopyralid	Post-emergent control of broadleaf weeds. Do not exceed maximum yearly rate of 0.5 pt.
1.25 to 2 pt Treflan HFP 4 E	0.6 to 1 trifluralin	For control of annual grasses and broadleaf weeds. Apply and incorporate in spring before transplanting. Check label for direct seeded cole crops. Rate for Chinese Brassica vegetables is 1 to 1.5 pt.

DISEASE CONTROL: Cole Crops

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Alternaria Leaf Spot					
Cabrio and pyraclostrobin[4] generics	11	0	12 to 16 oz[5]	4 apps	
Chlorothalonil[4]					There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Bravo Ultrex	M	7	1.4 lb	14.5 lb	
Bravo Weather Stik	M	7	1.5 pt	11.7 pt	
Dexter Max	M/11	7	2 to 2.25 lb	13.7 lb	Use at least 10 gal/A spray volume.
Endura	7	0	6 to 9 oz	2 apps	
Copper, fixed coppers[6]	M				See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Dithane M45 and mancozeb[4] generics	M	7	2 lb		There are multiple Dithane formulations and mancozeb generics on the market. See label for rates.
Flint Extra	11	0	3.0 to 3.8 oz	7.6 oz	
Fontelis	7	0	14 to 30 fl oz[5]	72 fl oz	
Inspire Super	3/9	7	16 to 20 fl oz	80 fl oz	
Luna Sensation	7/11	0	5.0 to 7.6 fl oz	15.3 fl oz	
ManKocide	M	7	1 to 3 lb	8.8 lb	Broccoli & cabbage only.
Omega 500F	29	7	15.35 fl oz	5.75 pt	
Priaxor	7/11	3	6 to 8.2 fl oz	3 apps	
Procure 480 SC	3	1	6 to 8 fl oz[5]	18 fl oz	Black spot (*Alternaria* spp.) only.

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DISEASE CONTROL: Cole Crops *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Quadris and azoxystrobin[4] generics	11	0	6 to 15.5 fl oz[5]	3 foliar apps	
Quadris Top	11/3	1	12 to 14 fl oz[5]	56 fl oz	
Reason 500 SC	11	2	8.2 fl oz	24.6 fl oz	
Rhyme	3	7	5 to 7 fl oz	4 apps	
Switch 62.5 WG	9/12	7	11 to 14 oz	56 oz	
Topguard EQ	3/11	7	5.0 to 8.0 fl oz	4 apps	Observe season limits for group 3 and group 11 fungicides.
Trionic	3	1	6 to 8 fl oz	2 apps	
Black Leg					
Cabrio and pyraclostrobin[4] generics	11	0	12 to 16 oz[5]	4 apps	
Priaxor	7/11	3	6 to 8.2 fl oz	3 apps	
Rovral and iprodione[4] generics	2	0	2 pt	2 apps	Broccoli only. Apply after thinning as a directed spray targeting the base of the plant and adjacent soil surface; make a 2nd application no later than the day of harvest.
Black Rot (*Xanthamonas*)					
Actigard	21	7	0.5 to 1 oz	4 apps	Suppression only. Apply 7 to 10 days after thinning and make up to three additional applications. Apply in a minimum of 20 gal/A of water. May be applied through drip irrigation. May cause phytotoxicity and yield reduction. Do not apply to stressed or injured plants.
Copper and fixed coppers[6]	M				See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Clubroot					
Blocker 10G	14	0	5.15 lb/1,000 linear feet of row	225 lb	Banded or broadcast pre-transplant treatment.
Blocker 4F	14	0		1 app	Apply at transplanting in furrow or band application. See label for rates and application instructions.
Omega 500 and fluazinam[4] generics	29	7/50		1 app	Apply before or at transplanting, in furrow or band application. See label for rates and application instructions.
Ranman	21	0		1 app	Apply before or at transplanting. See label for rates and application instructions.
Damping-off (*Rhizoctonia*), Wirestem					
Blocker 4F	14	0	2.8 to 3.8 gal	1 app	May be applied as a plant drench or banded spray. See label for specific applications instructions.
Blocker 10G	14	0			
Damping-off (*Pythium*)					
MetaStar and metalaxyl[4] generics	4	0		1 app	Preplant or post plant incorporation, broadcast or banded. Can be applied by drip irrigation. See label for rates and specific application instructions. May be tank mixed with Terraclor for control of club root.
Presidio	43	2	3 to 4 fl oz	12 fl oz	Can be applied as a drench or through drip irrigation at planting; soil-directed applications can be made during the season.
Ridomil Gold and mefenoxam[4] generics	4	0		1 app	Preplant or at planting, broadcast or banded. Can be applied by drip irrigation. See label for rates and specific application instructions.

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DISEASE CONTROL: Cole Crops *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Downy Mildew					
Actigard	21	7	0.5 to 1 oz	4 apps	Apply 7 to 10 days after thinning and make up to three additional applications every 7 days. May be applied through drip irrigation. May cause phytotoxicity and yield reduction. Do not apply to stressed or injured plants.
Cabrio and pyraclostrobin[4] generics	11	0	12 to 16 oz[5]	4 apps	
Chlorothalonil[4]					There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Bravo Ultrex	M	7	1.4 lb	14.5 lb	
Bravo WeatherStik	M	7	1.5 pt	16 pt	
Copper, fixed coppers[6]					See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Dithane M45 and mancozeb[4]	M	7	1.5 lb	12.8 lb	Broccoli and cabbage only. There are multiple Dithane formulations and mancozeb generics on the market. See label for rates.
Forum	40	7	6 fl oz	30 fl oz	Tank-mix with another fungicide NOT in FRAC Group 40.
Luna Sensation	7/11	0	7.6 fl oz	15.3 fl oz	Suppressive only.
Micora	40		5.5 to 8.0 fl oz	2 apps	Transplant production only.
Omega 500 and fluazinam[4] generics	29	7	15.35 fl oz	5.75 pt	Cabbage only.
Orondis Opti	49	7	1.75 to 2.5 pt	10 pt	Do not combine with soil applications of Orondis Gold.
Presidio	43	2	3 to 4 fl oz	4 apps	Apply every 7 to 14 days. Tank-mix with another fungicide NOT in FRAC Group 43.
Quadris and azoxystrobin[4] generics	11	0	6 to 15.5 fl oz[5]	3 foliar apps	
Ranman	21	0	2.75 fl oz	5 apps	Leafy brassicas only. Tank-mix with an organosilicone surfactant.
Reason 500 SC	11	2	5.5 to 8.2 fl oz	24.6 fl oz	
Revus	40	1	8 fl oz	32 fl oz	Use a spreader/penetrant surfactant. Tank-mix with another fungicide NOT in FRAC Group 40.
Ridomil Gold Bravo SC	4/M	7	1.5 pt	4 apps	Do not apply to loosehead Chinese cabbage. Observe seasonal limits for chlorothalonil.
Ridomil Gold and mefenoxam[4] generics	4	7	0.25 to 0.5 pt	1 pt	Tank-mix with another fungicide labeled for downy mildew. Not recommended for fields where downy mildew is already established.
Zampro	40/45	0	14 fl oz	3 apps	
Phytophthora Root Rot, Basal Stem Rot					
Presidio	43	2	3 to 4 fl oz	12 fl oz	Can be applied as a drench or through drip irrigation at planting; soil-directed applications can be made during the season.
Sclerotinia Stem Rot					
Contans	-	0	1 to 4 lb	8 apps	OMRI-listed. Use pre-season and incorporate into soil. See label for specific instructions.
Cueva	M	0	0.5 to 2 gal	n/a	OMRI-listed. Mix in 100 gallons of water, use 50 to 100 gal/A of solution.
Endura	7	0	6 to 9 oz	2 apps	
Fontelis	7	0	16 to 30 fl oz[5]	72 fl oz	
Luna Sensation	7/11	0	7.6 fl oz	15.3 fl oz	

1 Products with numerical FRAC codes must be alternated or tank-mixed with products that have a different FRAC code to discourage resistance development. See product label for maximum number of consecutive applications allowed. Refer to the table on pages 22-24 for more information on FRAC codes.
2 Pre-harvest interval.
3 Per 100 gal of water.
4 Generic products available (Appendix F). Amounts and seasonal limits per acre are product dependent.
5 Use higher rate when pressure is severe.
6 Fixed coppers labeled in KY include: Badge SC, Badge X2, Basic Copper 53, Champ, Champ WG, ChampION++, C-O-C-S WDG, Cueva, Cuprofix, Cuproxat, Kentan, Kocide 2000, Kocide 3000, Kocide DF, KOP-5, MasterCop, Nordox 75 WG, Nu-Cop 30 HB, Nu-Cop 50DF, Phyton 27, Phyton 35, and Previsto. Rates may vary by product and by crop. Refer to specific product label for this information.

Sweet Corn

Grass family (Poaceae): *Zea mays* subsp. *mays*

Types and Isolation Requirements

An array of high-sugar sweet corn types are found in the most recent seed company catalogs. Varieties are often grouped under abbreviations for the types of genes they carry for sweetness (*su, se, sh2*, etc.) or under various trade names (TripleSweet™, Xtra Tender™, Sweet Generation™, etc.) that contribute to the confusion. Various types of sweet corn are strikingly different in terms of sweetness, eating quality, and suitability for mechanical harvest and shipping. Consider carefully which types are best suited to your marketing situation. Different types also have different isolation requirements.

Regardless of the type, the variety should have a tight husk cover over the ear tip to help keep out birds, sap beetles, and corn earworms.

Traditional or standard sweet corn (*su*) varieties are characterized by their creamy corn flavor and mild sugars; these sugars quickly convert to starch so these varieties are best consumed soon after harvest. Obviously, they are most suitable for local sales.

Sugary enhanced (*se)* varieties have tender kernels and a creamy texture like standard varieties but have up to twice as much sugar. Consequently, they will remain sweet longer than standard sweet corn. Sugary enhanced varieties are very popular at farmers' markets and for local sales.

Supersweet or shrunken-2 varieties (*sh* or *sh2*) all have shrunken, wrinkled/shriveled seeds. They have a high sugar content as well as slower conversion of sugar to starch. This means they will remain sweeter much longer than other corn types. Supersweets also have kernels that hold up much better when mechanically harvested; however, these tougher kernels do not have the creamy texture and flavor of standard or sugary enhanced corn varieties. Most sweet corn varieties sold for processing and through wholesale market channels are supersweets.

Augmented supersweets are new and improved supersweet varieties that have tender kernels like *se* varieties while retaining the added sweetness and longer shelf life of supersweets. Ears of these varieties contain only a single type of kernel. These varieties are sold under several trade names ('Xtra Tender™,' 'Gourmet Sweet™,' 'MultiSweet™,' 'HQ,' 'shQ,' etc.).

Synergistic varieties are sold under several trade names, including 'TripleSweet™,' 'Sweet Generation™,' 'Sweet Breed™,' 'Table Sweet™,' and 'seQ.' Ideally, they have the seed vigor of standard varieties, the flavor and eating quality of *se* varieties, and the high sugar and long shelf life of *sh2* varieties. Most synergistics combine the best characteristics of sugary enhanced and supersweet varieties with seed vigor that is most similar to *se* types. What distinguishes this group is that *different types of kernels occur on the same ear*; that is, most of these varieties have ears with ¾ sugary enhanced (*se*) type kernels and ¼ supersweet (*sh2*) kernels. These varieties may not have as long a shelf life as true supersweets and may not be suitable for mechanical harvest. The genetic combinations in these varieties differ widely, and growers should try them on a small scale prior to growing large acreages.

Genetically modified or transgenic sweet corn varieties are available that express a toxin from the insect-killing bacteria *Bacillus thuringiensis* (Bt). Bt toxins help control worms feeding on sweet corn and can result in considerable reductions in pesticide usage, especially late in the season. Any of the previously described sweet corn types can be modified in this way. Current transgenic sweet corn varieties are sold under the trade name 'Attribute™,' 'Performance Series™', or 'Attribute II™.' Recent studies have shown that the 'Attirbute I™' and 'Performance Series™' varieties may have significant corn earworm damage in some situations without the use of additional control measures. While Bt toxins are harmless to humans, some wholesale and retail buyers will not accept transgenic products. *Transgenic varieties also are not allowed in organic production.*

Isolation Requirements

All sweet corn types must be isolated from field corn or popcorn to prevent cross pollination and loss of sweetness. A separation (isolation) distance of 700 feet will give complete isolation of white, yellow, or high-sugar varieties but may be impractical. A distance of 250 feet will result in some contamination but not enough to affect quality. Isolation can also be maintained by a 10- to 14-day difference in maturities of different types, although isolation by distance is more effective.

The different types of sweet corn described in the "Varieties" table can be placed in either of two major groups in terms of their isolation requirements. While each type within one of these groups may benefit from isolation from other types in the same group, the resulting cross pollination will not produce field corn kernels. *Cross pollination between the two groups, however, will produce a percentage of unacceptable kernels*. These lists

SWEET CORN ISOLATION GROUPS

Group 1	Standard varieties (su)
	Sugary enhanced (se)
	Synergistics
	Sweet Breed
	Table Sweet
	TripleSweet
	seQ, HQ
Group 2	Supersweets (sh-2)
	Augmented supersweets
	Crisp N Sweet
	Gourmet Sweet
	MultiSweet
	SummerSweet
	shQ

may not include all the trade names currently available.

Planting and Culture

Sweet corn will do well in all areas of Kentucky, but well-drained soils are essential for good results. Fescue sod is ideal prior to sweet corn production. Sweet corn makes a good rotational crop for other vegetable crops. A well-prepared seedbed is critical for successful seed germination and good stands. Disking the soil three to four times before planting will help in preparing a good seedbed. Plowing should be done several weeks in advance of planting to allow the ground to settle and the grass to decompose. Ten to 15 pounds of seed will usually be required to plant an acre. Plant seed in rows 30 to 40 inches apart with plants spaced 8 to 10 inches apart in the row. If plants are spaced closer, thin to 8 inches within row spacing. Ears will be smaller if planted too close together.

For best results, sweet corn seed should be planted after the soil temperature has reached 60°F. In most parts of Kentucky, the earliest plantings can be made from April 20 to May 1 (see Appendix K). The harvest period for sweet corn can be extended by planting early, midseason, and late-maturing varieties or by making successive plantings at weekly intervals. Late-planted sweet corn will have more insect and disease problems. Cultivars with tolerance or resistance to leaf blights and viruses should be selected when planting in June, especially in river bottoms and humid areas in the state (see "Varieties" table).

Seed-germination percentages of some supersweet varieties (or other varieties with shrunken seed) can be poor to fair, particularly under cold soil conditions. Make sure the soil is warmer than 60°F before planting these varieties. The germination of sugary enhanced corn is much better than that of shrunken types but not quite as good as standard sweet corn. At present, use standard varieties for very early plantings intended for early markets. Most high sugar corn varieties are also more attractive to insects, birds, groundhogs, and raccoons and more susceptible to heat and drought stresses than standard sweet corn.

Irrigation is usually required to ensure high quality in both standard and high-sugar corn types. While solid set sprinkler systems and traveling guns are still in use, it is also relatively easy to irrigate (and fertigate) sweet corn simply by running drip irrigation lines down the rows on bare ground with lines placed no more than about 4 inches from the plants.

Production with Plasticulture

A number of Kentucky growers have successfully grown transplanted sweet corn on plastic mulch with drip irrigation. This system enables earlier harvests, resulting in considerably higher market prices. Typically seeds are sown in 128 cell trays with two seeds per cell. Transplants should be planted between 14 and 18 days after seeding. It is critical that corn transplants not be held over too long in the greenhouse, as this results in permanent stunting of the plants in the field. Also, *do not use early-maturing varieties (earlier than 75 days) as these will tend to tassel prematurely, resulting in stunted plants with non-marketable ears*. Growers may want to consider multiple seeding times in case unfavorable weather prevents transplanting in a timely fashion. Typically seed is inexpensive compared to the cost of using the plasticulture system.

Black plastic mulch on raised beds is most often used for transplanted corn. One popular system uses double rows (two rows per bed) with 12 inches between transplants in the row and about 18 to 20 inches between the two rows. In the latter system two seeds are sown in each cell of the plug trays; therefore, each hill will contain two plants in the field. Some growers have also direct seeded sweet corn under clear plastic and then cut the plastic open after the seedlings emerged. Using clear plastic, however, has resulted in problems with weed seed germination under the plastic.

Fertilizing

Make all lime and fertilizer applications based on soil test results. Sweet corn tolerates some soil acidity and can be grown in soils ranging in pH from 5.5 to 6.8; however, lime should be applied to bring the pH to 6.5 for best results. Where sweet corn is planted on sod ground, apply at least half of the fertilizer broadcast and plow down. The remaining fertilizer can be applied broadcast just before planting and disked in. If banding equipment is available, fertilizer may be banded 2 to 3 inches to the side of seed and 2 to 3 inches deeper than the seed. The total amount of fertilizer that is banded should not exceed 45 pounds per acre (total of N and K, to avoid root burn from salts). Sidedress with 50 pounds of actual nitrogen (N) when plants are about knee high. High-sugar varieties (supersweets, sugary enhanced, and others) benefit from an additional late sidedressing of nitrogen to keep the husks dark green.

With plasticulture systems, apply all P and K and half to two-thirds of the nitrogen prior to planting. The remaining nitrogen requirement can be divided up into equal doses and fertigated weekly.

Sweet corn grown on high pH soils that are also very high in available phosphorus may show zinc deficiency in some years. However, many other factors, including weather conditions and cool soil temperatures, affect availability of soil zinc, making it difficult to predict a response to added zinc for a specific growing season. Zinc should be broadcast at 30 pounds per acre (90 pounds of zinc sulfate) or banded at 6 pounds per acre (17 pounds of zinc sulfate). A broadcast application should last from four to six years, whereas a band application should be made annually for six to eight years (see Appendix B).

Harvesting and Handling

Corn should be harvested at the milk stage of maturity for best quality. Sweet corn is usually marketed as five dozen ear units in bags or crates. Harvest in the early morning while

the air is still cool. If the temperature of the ears is high when harvested, field heat should be removed by plunging them in ice water. To maintain top quality, sweet corn must be cooled to as near to 32°F as possible. This prevents sugars from changing to starch. Crated corn can be cooled in ice water from about 86°F to around 41°F in about 80 minutes. Hydrocoolers are often used by larger producers for this purpose. Vacuum cooling is a much faster procedure but involves more expensive equipment. Store sweet corn at 32°F and 90 to 95 percent relative humidity. The type of sweet corn grown also has a great impact on sweetness and shelf life.

VARIETIES: Sweet Corn and Ornamental Corn

Variety	DTM[1]	Color[2]	Comments
STANDARD SWEET CORN (SU)			
Merit	80	Y	Rust and northern corn leaf blight resistance, long ears.
Silver Queen	95	W	Rust resistant, one of the most popular sweet corn varieties.
SUGAR ENHANCED (SE) AND SYNERGISTICS (SEQ)			
Profit	70	BC	Attractive husks and ears, intermediate resistance to northern corn leaf blight, common rust and Stewart's wilt.
Temptation	72	BC	Good for early spring plantings, good yields.
Kristine	75	BC	Resistance to rust and southern corn leaf blight
Essence	78	BC	Attractive husk, short flags, very sweet kernels, high yield, intermediate resistance to northern corn leaf blight, common rust and Stewart's wilt.
Montauk	79	BC	Resistance to Stewart's wilt and northern corn leaf blight
Providence	80	BC	Good strong mid-season variety, rust resistant
Incredible RM	85	Y	Resistant to Stewart's wilt, rust, northern corn leaf blight, and maize dwarf mosaic virus, good husk coverage, excellent flavor.
Mirage	78	W	Attractive husk, and 7.9 inch ear, shucks easily, intermediate resistance to northern corn leaf blight, common rust and Stewart's wilt.
Mattapoisett	80	W	Attractive husk, 8 inch ears, long flags, intermediate resistance to northern corn leaf blight, common rust and Stewart's wilt.
Silver King	82	W	Attractive husk and 7.6 inch ear, long flags, snaps from plant easily, intermediate resistance to northern corn leaf blight, common rust and Stewart's wilt.

(continued)

VARIETIES: Sweet Corn and Ornamental Corn *(continued)*

Variety	DTM[1]	Color[2]	Comments
Argent R/M	83	W	Resistance to rust, Stewart's wilt, maize dwarf mosaic virus, and northern corn leaf blight.
SUPERSWEETS (SH2 AND AUGMENTED SUPERSWEETS)			
AP 426	58	BC	Excellent husk cover, glossy 8 inch ear, high yield for early maturity.
Anthem XR	72	BC	Attractive husk, good yield, intermediate resistance to northern corn leaf blight and common rust.
Awesome	76	BC	Resistance to Stewart's wilt, good early type for shipping and farmers markets.
Munition	78	W	Attractive husks and 7.5 inch ears, good disease resistance and very high yield.
Obsession	79	BC	Resistance to rust, Stewart's wilt, and northern corn leaf blight, excellent husk cover, tip fill, and yield.
GENETICALLY MODIFIED[3]			
Obsession II (sh2)	79	BC	Resistance to rust, Stewart's wilt, and northern corn leaf blight, excellent husk cover, tip fill, and yield, Performance Series hybrid tolerant to Roundup brand herbicides with above and below ground insect control.
BSS 0977 (sh2)	79	BC	Resistance to rust, Stewart's wilt and northern corn leaf blight, Attribute® insect protection.
Aspire	80	Y	Attribute II trait stack, attractive husk, 8 inch ear snaps from husk easily, very sweet kernels.
Passion II (sh2)	80	Y	Resistance to rust, Stewart's wilt and northern corn leaf blight, Performance Series hybrid tolerant to Roundup brand herbicides with above and below ground insect control.
WH 0809 (se)	80	W	Resistance to rust and southern corn leaf blight, Attribute® insect protection.
BC 0805 (se)	83	BC	Resistance to rust, Attribute® insect protection.
ORNAMENTAL CORN[4]			
Earth Tones Dent	90		Colors are soft earth tones, 8 to 10 inch ears.
Green and Gold Dent	95-100		Bright yellow and green kernels, 8 to 10 inch ears.
Mini Blue	100		Shiny blue kernels, 2 to 4 inch ears, good stalks, popcorn.
Mini Pink,	100		Shiny pink kernels, 2 to 4 inch ears, good stalks, popcorn.

(continued)

VARIETIES: Sweet Corn and Ornamental Corn *(continued)*

Variety	DTM[1]	Color[2]	Comments
Autumn Explosion	102		Multicolored flint corn, 8 to 9 inch ears, 25% red husks.
Indian Fingers	110		Multicolored, 3.5 inch ears, small shiny kernels.
Pod Corn	110		Highly ornamental and variable with husks around each kernel.

1 Days to maturity
2 Y = yellow; W = white; BC = bicolor
3Growers should check current regulations for marketing and labeling of transgenic or "genetically modified" crops before planting; "Attribute" sweet corn seed may also have minimum purchase requirements.
4See HO-81, Ornamental Corn Production in Kentucky, for production and more detailed variety information.

FERTILIZER: Sweet Corn

Soil Test Results (lb/A)		Fertilizer Needed (lb/A)
Phosphorus		**Phosphate (P_2O_5)**
Low	<31	121-180
Medium	31-60	61-120
High	61-80	1-60
Very High	>80	0
Potassium		**Potash (K_2O)**
Low	<201	151-200
Medium	201-300	101-150
High	>300	100
Nitrogen		**N**

Apply 80 to 100 lb actual nitrogen (N)/A preplant; apply at least 40 to 50 lb N/A as sidedressing when plants are knee high.

PESTICIDE SAFETY: Sweet Corn

	Signal[1]	Re-entry (hrs)	Harvest (days)[2]
INSECTICIDES			
Assail 30 SG	C	12	1/7
Avaunt eVo 30 DG	C	12	3
Blackhawk 36 WG	C	4	1/7/28[4]
Bt products	C	12	0
Coragen 1.67 SC	-	4	1
Intrepid 2 F	C	4	3
Intrepid Edge	C	4	3/21[4]
Malathion 8	C	12	5
Oberon 2 SC	C	12	5
Radiant SC	C	4	1
Rimon 0.83 EC	W	12	1
Sevin XLR Plus	W	12	2
Sivanto Prime 1.67 SL	C	4	7
Transform 50 WG	D	24	7
Vantacor 5 SC	-	4	7

(continued)

PESTICIDE SAFETY: Sweet Corn *(continued)*

	Signal[1]	Re-entry (hrs)	Harvest (days)[2]
Restricted Use			
Agri-Mek 0.7 SC	W	12	7
Asana XL	W	12	1
Aztec HC	W	48	AP
Baythroid XL	W	12	0
Besiege 0.835 CS	W	24	[1]
Brigade 2 EC	W	12	1/30[4]
Counter 20 G	DP	48	AP
Diazinon AG500	C	24	7
Fastac 0.83 EC	D	12	3
Elevest 2.22 SC			
Force 3 G	C	0	AP
Lannate 90 SP	DP	48	0
Mocap 15 G	W	48	AP
Mustang Maxx	W	12	3
Permethrin 3.2 EC	C	12	3
Pounce 1.5 G	C	12	1
Proaxis 0.5 EC	C	24	1
SmartChoice HC	W	48	AP
Thimet 20 G	DP	48	AP
Warrior II	W	24	1
FUNGICIDES			
Aftershock	C	12	7
Aproach	C	12	7
Azoxystrobin[3]	C	4	7
Dexter Max	C	24	7
Dexter XCEL	C	19 days	7/49
Elatus	C	12	7
Evito 480/Evito T	C	12	7
Fixed coppers[3,5]	D	24/48	0
Headline	W	12	7
Headline SC	W	12	7
Headline AMP	W	12	7
Mancozeb[3]	C	24	7
Miravis Neo	W	12	14
Muscle ADV	C	12	14/21/36
Priaxor	C	12	7
Propiconazole[3]	W	24	14
Propiconazole + Azoxystrobin[3]	W	12	14
Prosaro	C	12	7
Quilt	C	24	14
Quilt Xcel	W	12	14
Stratego	W	12	14
Stratego YLD	C	48	0
Tebuconazole[3]	W	19 days	7
Vertisan	W	12	7
Fresh market only			
Chlorothalonil[3]	D	48	14

1 W: Warning, C: Caution, D: Danger; P: Poison
2 AP: At planting, ST: Seed treatment.
3 Several formulations are marketed. See the general introduction for more details on fungicides.
4 Dependent on application type, see label.
5 Re-entry period varies by product. See label for more information.

INSECT CONTROL: Sweet Corn[1,2,3]

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
PLANTING TIME			
Seedcorn Maggots, Rootworms, Seedcorn Beetles: Corn rootworms are a potential pest where corn is grown year after year in the same field.			
Aztec 2.1 G	6.7 oz/1,000 row-feet		Band, T-band or furrow.
Aztec 4.67 G	3 oz/1,000 row-feet		Band, T-band or furrow.
Brigade 2 EC	0.3 fl oz/1,000 row-feet		Spray as T-band over open furrow.
Counter 20 G	4.5 to 6 oz/1,000 row-feet		Band or furrow.
Force 3 G	4 to 5 oz/1,000 row-feet		T-band controls cutworms as well.
Mocap 15 G	8 oz/1,000 row-feet		Band only. Rootworm control.
Thimet 20 G	4.5 to 6 oz/1,000 row-feet		Band only. Rootworm control.
FOLIAR TREATMENTS			
Armyworms			
Asana XL	5.8 to 9.6 fl oz	96 fl oz	-
Baythroid XL	1.6 to 2.8 fl oz	28 fl oz	Limit 2.8 fl oz per 2-day interval.
Blackhawk 36 WG	1.67 to 3.3 oz	20 oz	-
Brigade 2 EC	2.1 to 6.4 fl oz	12.8 fl oz	Do not graze livestock for 1 day.
Coragen 1.67 SC	3.5 to 7.5 fl oz	15.4 fl oz	Limit 4 applications.
Fastac 0.83EC	2.8 to 3.8 fl oz	11.4 fl oz	Allow 3 to 5 days between applications.
Intrepid 2 F	4 to 16 fl oz	64 fl oz	-
Lannate 90 SP	0.25 to 0.5 lb	7 lb	-
Mustang Maxx	2.8 to 4 fl oz	24 fl oz	Allow 3 to 5 days between applications.
Radiant SC	3 to 6 fl oz	36 fl oz	Allow 2 days between applications.
Rimon 0.83 EC	6 to 12 fl oz	60 fl oz	Allow 7 days between applications.
Sevin XLR Plus	1 to 2 qt	16 qt	Allow 3 days between applications.
Warrior II	1.28 to 1.92 fl oz	30.7 fl oz	Allow 3 to 5 days between applications.
Corn Earworms: Corn earworm is the key insect pest attacking sweet corn. Egg laying occurs only while silks are still green, and sprays need to be repeated at 2- to 7-day intervals while silks are green. Time of planting, intensity of moth flight, and temperature will affect spray intervals. Pheromone traps are available for monitoring this pest and determining spray intervals. Pyrethroid insecticides are not as effective as in the past when used later in the sweet corn season.			
Asana XL	5.8 to 9.6 fl oz	96 fl oz	-
Baythroid XL	1.6 to 2.8 fl oz	11.2 fl oz	Limit 2.8 fl oz per 7-day interval.
Besiege 0.835 CS	6 to 10 fl oz	31 fl oz	Allow at least 1 day between applications.
Blackhawk 36 WG	2.2 to 3.3 oz	20 oz	-
Brigade 2 EC	2.1 to 6.4 fl oz	12.8 fl oz	Do not graze livestock for 1 day.
Coragen 1.67 SC	3.5 to 7.5 fl oz	15.4 fl oz	Limit 4 applications.
Fastac 0.83EC	2.8 to 3.8 fl oz	11.4 fl oz	Allow 3 to 5 days between applications.
Intrepid Edge	8 to 12 fl oz	51 fl oz	Limit 6 applications. Allow 2 days between applications.
Lannate 90 SP	0.25 to 0.5 lb	7 lb	-
Mustang Maxx	2.8 to 4 fl oz	24 fl oz	Allow 3 to 5 days between applications.
Permethrin 3.2 EC	4 to 8 fl oz	32 fl oz	Allow 3 days between applications.
Proaxis 0.5 EC	2.56 to 3.84 fl oz	15.36 fl oz	Allow 3 to 5 days between applications.
Radiant SC	3 to 6 fl oz	36 fl oz	Allow 2 days between applications.
Rimon 0.83 EC	6 to 12 fl oz	60 fl oz	Allow 7 days between applications. Mix with an adulticide to improve control.
Warrior II	1.28 to 1.92 fl oz	30.7 fl oz	-
Corn Leaf Aphids			
Asana XL	5.8 to 9.6 fl oz	96 fl oz	-
Assail 30 SG	2.1 to 2.9 oz	11.2 oz	Limit 2 applications. Allow 7 days between applications.
Sivanto Prime 1.67 SL	7 to 14 fl oz	28 fl oz	Allow 7 days between applications.
Transform 50 WG	0.75 to 1 oz	3 oz	Limit 2 applications. Allow 14 days between applications.
Cutworms: Eliminate weeds from field margins and plow fields at least 2 weeks before planting to destroy cutworm food sources and egg laying sites.			
Asana XL	5.8 to 9.6 fl oz	96 fl oz	-
Baythroid XL	0.8 to 1.6 fl oz	11.2 fl oz	Limit 2.8 fl oz per 7-day interval.
Brigade 2 EC	2.1 to 6.4 fl oz	12.8 fl oz	Do not graze livestock for 1 day.
Fastac 0.83EC	2.2 to 3.8 fl oz	11.4 fl oz	Allow 3 to 5 days between applications.
Mustang Maxx	2.24 to 4 fl oz	24 fl oz	Allow 3 to 5 days between applications.

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INSECT CONTROL: Sweet Corn[1,2,3] *(continued)*

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Permethrin 3.2 EC	4 to 8 fl oz	32 fl oz	Allow 3 days between applications.
Warrior II	1.28 to 1.92 fl oz	30.7 fl oz	Allow 3 to 5 days between applications.
European Corn Borer, Southwestern Corn Borer: Treat if more than 15% of the whorls are infested with live larvae. Pheromone traps are available to monitor this pest. Corn borer control is frequently necessary when tassels begin to emerge from the whorl.			
Asana XL	5.8 to 9.6 fl oz	96 fl oz	
Avaunt eVo 30 DG	2.5 to 3.5 oz	14 oz	Allow 3 days between applications. Until tassel push only. For European corn borer.
Baythroid XL	1.6 to 2.8 fl oz	11.2 fl oz	Limit 2.8 fl oz per 7-day interval.
Blackhawk 36 WG	1.67 to 3.3 oz	20 oz	-
Bt products	See labels		-
Brigade 2 EC	2.1 to 6.4 fl oz	12.8 fl oz	Do not graze livestock for 1 day.
Coragen 1.67 SC	3.5 to 7.5 fl oz	15.4 fl oz	Limit 4 applications.
Fastac 0.83EC	2.2 to 3.8 fl oz	11.4 fl oz	Allow 3 to 5 days between applications.
Intrepid 2 F	4 to 8 fl oz	64 fl oz	-
Lannate 90 SP	0.25 to 0.5 lb	7 lb	-
Mustang Maxx	2.8 to 4 fl oz	24 fl oz	Allow 3 to 5 days between applications.
Permethrin 3.2 EC	4 to 8 fl oz	32 fl oz	Allow 3 days between applications.
Proaxis 0.5 EC	2.56 to 3.84 fl oz	15.36 fl oz	Allow 3 to 5 days between applications. For Southwestern corn borer.
Radiant SC	3 to 6 fl oz	36 fl oz	Allow 2 days between applications. For Southwestern corn borer.
Rimon 0.83 EC	6 to 12 fl oz	60 fl oz	Allow 7 days between applications. For European corn borer.
Warrior II	1.28 to 1.92 fl oz	30.7 fl oz	Allow 3 to 5 days between applications.
Fall Armyworms: can be a serious pest only of sweet corn planted after June 1. Treat if more than 10% of the whorls are infested with live larvae. Pheromone traps are available to monitor this pest.			
Avaunt eVo 30 DG	2.5 to 3.5 oz	14 oz	Allow 3 days between applications. Until tassel push only.
Blackhawk 36 WG	1.67 to 3.3 oz	20 oz	-
Bt products	See labels	-	-
Coragen 1.67 SC	3.5 to 7.5 fl oz	15.4 fl oz	Limit 4 applications.
Lannate 90 SP	0.25 to 0.5 lb	7 lb	-
Radiant SC	3 to 6 fl oz	36 fl oz	Allow 2 days between applications.
Flea Beetles			
Asana XL	5.8 to 9.6 fl oz	96 fl oz	-
Assail 30 SG	4 to 5.3 oz	11.2 oz	Limit 2 applications. Allow 7 days between applications.
Brigade 2 EC	2.1 to 6.4 fl oz	12.8 fl oz	Do not graze livestock for 1 day.
Fastac 0.83EC	2.2 to 3.8 fl oz	11.4 fl oz	Allow 3 to 5 days between applications.
Mustang Maxx	2.24 to 4 fl oz	24 fl oz	Allow 3 to 5 days between applications.
Permethrin 3.2 EC	4 to 8 fl oz	32 fl oz	Allow 3 days between applications.
Proaxis 0.5 EC	2.56 to 3.84 fl oz	15.36 fl oz	Allow 3 to 5 days between applications.
Sevin XLR Plus	1 to 2 qt	16 qt	Allow 3 days between applications.
Warrior II	1.28 to 1.92 fl oz	30.7 fl oz	Allow 3 to 5 days between applications.
Corn Rootworm Beetles, Grasshoppers, Japanese Beetle, Sap Beetle: Select sweet corn cultivars with good tip coverage. Treat when necessary.			
Asana XL	5.8 to 9.6 fl oz	96 fl oz	-
Assail 30 SG	4 to 5.3 oz	11.2 oz	Limit 2 applications. Allow 7 days between applications.
Baythroid XL	1.6 to 2.8 fl oz	11.2 fl oz	Limit 2.8 fl oz per 7-day interval.
Brigade 2 EC	2.1 to 6.4 fl oz	12.8 fl oz	Do not graze livestock for 1 day.
Fastac 0.83EC	2.2 to 3.8 fl oz	11.4 fl oz	Allow 3 to 5 days between applications.
Mustang Maxx	2.24 to 4 fl oz	24 fl oz	Allow 3 to 5 days between applications.
Permethrin 3.2 EC	4 to 8 fl oz	32 fl oz	Allow 3 days between applications.
Proaxis 0.5 EC	2.56 to 3.84 fl oz	15.36 fl oz	Allow 3 to 5 days between applications.
Sevin XLR Plus	1 to 2 qt	16 qt	Allow 3 days between applications.
Warrior II	1.28 to 1.92 fl oz	30.7 fl oz	Allow 3 to 5 days between applications.
Stink Bugs			
Baythroid XL	1.6 to 2.8 fl oz	11.2 fl oz	Limit 2.8 fl oz per 2-day interval.

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INSECT CONTROL: Sweet Corn[1,2,3] *(continued)*

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Besiege 0.835 CS	6 to 10 fl oz	31 fl oz	Allow at least 1 day between applications. Limit 4 applications.
Brigade 2 EC	2.1 to 6.4 fl oz	12.8 fl oz	Do not graze livestock for 1 day.
Lannate 90 SP	0.5 lb	7 lb	Limit 28 applications. Allow at least 1 day between applications.
Warrior II	1.28 to 1.92 fl oz	30.7 fl oz	Allow 3 to 5 days between applications.

1 See also Kentucky Insect Integrated Pest Management Scout Manual (IPM-10) for more information on sweet corn pests and their control.
2 See An IPM Scouting Guide for Common Problems of Sweet Corn in Kentucky (ID-184) for photos of pests.
3 Generic products available (Appendix G).

WEED CONTROL: Sweet Corn

Product Amt/A	lb A.I./A	Comments
2 to 4 pt Aatrex 4L	1 to 2 atrazine	For control of annual grasses and broadleaf weeds. Apply after planting but before weeds are 1 inch tall. Best in combination with alachlor or s-metolachlor. Do not plant any crop but corn for 18 months if using 1 lb or more atrazine because of residual injury. Do not use atrazine exclusively because resistance has occurred in certain weed species. Restricted use pesticide.
0.33 to 1.33 oz Accent 75 DF	0.015 to 0.06 nicosulfuron	For post-emergence control of grasses and broadleaves. Apply broadcast or with drop nozzles (post-direct) when corn up to 12 inches tall or V5 leaf stage. For corn 12 to 18 inches tall, apply only as post-direct. Max. 1 application/season.
0.5 to 1.6 fl oz Aim 1.9 EW	0.008 to 0.025 carfentrazone	For contact post-emergence control of annual broadleaf weeds and suppression of annual grasses. Can be applied as a preplant, pre-transplant burndown, or before crop emerges to actively growing weeds up to 4 inches tall. Can also be applied post-emergence as a directed hooded application between crop rows to corn with 8 to 14 leaf collars stage. Use min. 10 gal water/A and crop oil 1% v/v. Max. rate 2 fl oz/A.
1 to 2 pt Basagran	0.5 to 1 bentazon	Use post-emergence for control of annual broadleaves and suppression of yellow nutsedge. Use 2 applications for nutsedge control. Best if tank-mixed with other corn herbicides. Do not graze treated corn before 12 days after application.
2.1 to 2.58 qt Bicep II Magnum	1.6 to 2 atrazine + 1.2 to 1.56 s-metolachlor	Apply preplant or pre-emergence for control of most annual grasses and broadleaves. Do not use if small grains are to be planted the same year or if vegetable crops or tobacco are to be planted the following year. Conduct a soil test analysis for atrazine residue before the second year planting. May be applied at 1.3 to 2.58 qt/A in min. 15 gal water as a post-emergence directed treatment on weeds < 2 leaf stage.
3 to 3.75 qt Bullet 4 F or Lariat 4 F	3 to 3.75 alachlor + atrazine	For control of many annual grasses and broadleaves. Apply to soil surface immediately after planting. See label for further directions and restrictions. Max. rate is 6.4 qt/A per year or 2 applications/year.
3 to 7.7 fl oz Callisto 4L	0.09 to 0.24 mesotrione	For pre-emergence (6 to 7.7 fl oz/A) and post-emergence (3 fl oz/A) control of annual broadleaves. Rainfall within 7 to 10 days is needed for activation. If no rain, a rotary hoe is suggested. Do not cultivate 7 days before or after application. Do not tank-mix with organophosphate or carbamate insecticide or with a grass herbicide.
4 pt Camix 3.67 E	1.84 s-metolachlor + mesotrione	For pre-emergence control of annual grasses and broadleaves. Camix may be applied up to 14 days before planting or as a broadcast application before corn emerges.
12 to 20 oz Define DF	0.45 to 0.75 Flufenacet	For pre-emergent control of many annual grasses and some broadleaf weeds. May be applied preplant surface or incorporated or early post-emergence.
1.3 to 1.7 pt Dual II Magnum 7.6 E	1.3 to 1.6 s-metolachlor	For control of most annual grasses and certain broadleaf weeds and suppression of yellow nutsedge. Apply preplant surface or incorporated, pre-emergence, post-emergence, or lay-by. See label for specific rates. Better control of seedling Johnson grass with higher rates. Small grains may be planted 4½ months following treatment. See label for other rotational crop restrictions.
6 to 7.5 pt Expert 9.45 E	6 to 10 atrazine + s-metolachlor + glyphosate	For pre-emergence control of grasses and broadleaves. Good coverage is essential for best results. Sprinkler irrigate a minimum of 2 hours after, but within 2 days of application. Apply ½ to 1 inch of water. If irrigation is not possible and rain does not occur within 2 days after application, weed control may be decreased.
5.4 to 6.6 pt Fultime 4 E	2.7 to 3.3 acetochlor + atrazine	For pre-emergence control of grasses and broadleaves. Apply preplant, pre-emergence incorporated or non-incorporated. Max. 1 application/season. 0.5 inch water can be used to incorporate the herbicide.

(continued on next page)

WEED CONTROL: Sweet Corn *(continued)*

Product Amt/A	lb A.I./A	Comments
2.0 to 4.0 pt Gramoxone Inteon	0.69 to 1.38 paraquat salt	For non-selective contact kill of annual grasses and broadleaf weeds and top-kill of perennial weeds. Apply before, during, or after planting but before crop emergence banded or broadcast. Use higher rate for heavy weed infestations. Add non-ionic surfactant 0.25% v/v. Can be applied post-emergence as a directed spray at 1.0 to 2.0 pt/A on corn at least 10 inches tall with nozzles arranged to spray the bottom 3 inches of the stalk. Shorter corn plants may be injured. **Paraquat product labels require applicators to take an EPA-approved training every 3 years to mix, load, and apply paraquat.**
3 to 4 pt Guardsman Max 5 EC	1.24 to 1.65 atrazine + 0.64 to 0.84 dimethenamid-P	Apply preplant surface or incorporated, pre-emergence, or post-emergence for control of most annual grasses and many broadleaf weeds and suppression of nutsedge. Preplant applications for use in min. tillage or no-tillage (15 to 45 days). If incorporated, apply min. 2 weeks before planting. For pre-emergence, rainfall or irrigation is needed for activation. For early post-emergence, apply to corn up to 12 inches tall.
1.5 to 3 pt Harness	1.3 to 2.6 acetochlor	For pre-emergence control of some grasses and broadleaves. Tank-mix with other herbicides for adequate weed control.
0.75 fl oz Impact 2.8 E	0.016 topramezone	For post-emergence control of broadleaves and grasses. Use MSO at 1 to 1.5% v/v. Max. 1 application/season. PHI = 45 days.
6 pt Lexar 3.7 E	2.7 atrazine + s-metolachlor + mesotrione	For pre-emergence control of broadleaves and grasses. Apply preplant or pre-emergence without incorporation. May be applied up to 14 days before planting. Max. 3.5 qt/season. Irrigation or rainfall is needed within 7 days for best results. PHI = 60 days.
2.5 to 3 qt Micro-Tech 4ME or 3.8 to 4.5 lb Partner 65 WDG	2.3 to 4 alachlor	For control of many annual grasses and broadleaves. Apply as preplant or pre-emergence. Use higher rate for control of lambsquarters, black nightshade, nutsedge, and seedling Johnson grass. Restricted use pesticide. Max. 1 application/year and 4 qt/A per year.
14 to 18 fl oz Outlook 6 E	0.65 to 0.84 dimethenamid-P	For control of annual grasses and broadleaf weeds and suppression of seedling Johnson grass. Can be applied preplant surface or incorporated, pre-emergence or post-emergence to corn up to 12 inches tall. Outlook can be applied through chemigation or mixed with bulk dry fertilizer. Check label for exact rate for your soil type. PHI = 50 days. Max. rate is 21 fl oz/season.
0.67 oz Permit 75 WG or 0.66 to 1 oz Sandea 75 DF	0.031 to 0.046 halosulfuron	For annual broadleaves and yellow nutsedge control. Apply post-emergence broadcast from the spike to lay-by stage. Avoid cultivation within 7days of application. Apply again as directed spray if needed and avoid spraying the plant whorl. Include 0.5% v/v non-ionic surfactant. Not all corn varieties are tested, so use Permit with caution on newly released varieties. Do not apply to 'Jubilee' sweet corn or any corn under stress. Do not use with soil-applied organophosphate insecticides and do not apply any organophosphate insecticide within 7 days before or 3 days after Permit application.
1 oz Priority 62W	0.04 carfentrazone + halosulfuron	For pre-emergence and post-emergence control of broadleaves. Apply post-emergence to actively growing weeds. Multiple applications are allowed, with no time restrictions between applications.
4 pt Princep 4 L	2 simazine	For pre-emergence control of broadleaves and grasses. Apply preplant or pre-emergence with or without incorporation. Read label for rotation restrictions. Max. 1 application/season.
2.4 to 3.6 pt Prowl 3.3 E	1 to 1.49 pendimethalin	For control of annual grasses and broadleaf weeds. For use in conventional tillage only. Plant corn at least 1.5 inches deep. Apply pre-emergence after planting but before crop or weeds emerge. Apply post-emergence to corn 20 to 24 inches tall or when it has 8 visible collars (V8). Max. 1 application/season.
16 to 22 fl oz Roundup WeatherMax 5.5L	0.69 to 0.94 glyphosate-salt	For non-selective post-emergence control of annual and perennial grasses and broadleaf weeds. Use only AMS 1 to 2% v/v. Adding a non-ionic surfactant can reduce weed control effectiveness. Corn must be at least 12 inches tall. Application with hooded sprayers is allowed. Min. 30 days before planting any non-labeled crop. With Roundup Ready varieties only, post emergence applications may be made over the top of corn through the 8 leaf-collar stage (V8) or until corn is 30 inches tall. Drop nozzles are recommended if corn is more than 24 inches tall and must be used if corn is more than 30 inches tall to prevent spraying into whorls. Do not apply to corn more than 30 inches tall if it has reached the reproductive stage. Do not exceed 3.3 qt. per acre prior to crop emergence. Do not exceed 44 fl. oz. per acre in a single application in the crop. Do not exceed 4.1 qt. per acre per growing season from emergence through crop height of 48 inches. Do not exceed 5.3 qt. per acre for all applications.
0.6 to 1.3 pt Starane 1.5L	0.11 to 0.22 fluroxypyr	For post-emergence control of broadleaf weeds. Apply broadcast or band to corn up to 4 leaf collars (V4). After V4 stage, apply only as a directed treatment with drop nozzles. Max. 2 applications or 1.3 pt/A per season. PHI = 31 days. See label for control of volunteer potato vine.

(continued on next page)

WEED CONTROL: Sweet Corn *(continued)*

Product Amt/A	lb A.I./A	Comments
1.5 to 2.5 pt Surpass 6.4 E	1.2 to 2 acetochlor	For pre-emergence control of broadleaves and grasses and yellow nutsedge. Apply and incorporate up to 2 weeks preplant or anytime from 14 to 30 days prior to planting or after planting but prior to corn emergence.
1.6 to 4.0 oz TriCor DF	0.075 to 0.19 metribuzin	Pre-emergent control of grasses and broadleaves, tank-mix with other herbicides for adequate weed control. See label for mix options.
1 to 2 pt Weedar 64 4L	0.5 to 1.0 2,4-D amine salt	For selective post-emergence control of broadleaf weeds. Apply 7 to 14 days preplant at 1 to 2 pt/A. Apply 3 to 5 days after planting but before corn emerges at 2 pt/A. When corn is 8 inches tall, apply over top of corn at 0.5 to 1.0 pt/A to control small weeds. When corn is over 8 inches tall, use a drop nozzle at 0.5 to 1.0 pt/A. Avoid drift to other crops. 2,4-D may injure some supersweet (sh2, SE) cultivars. PHI 45 days on sweet corn.
1.5 to 4.0 oz Zidua	0.0796 to 0.213 pyroxasulfone	Rate ranges based on soil texture. Seed must be planted a minimum of 1 in. deep. PHI=37 days. See label regarding tank mixtures.

DISEASE CONTROL: Sweet Corn

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Leaf Blights, Gray Leaf Spot, Rust					
Aftershock and fluoxastrobin[4] generics	11	7	2 to 3.8 fl oz	4 apps	
Aproach	11	7	3 to 12 fl oz[4]	36 fl oz	Apply before disease onset.
Chlorothalonil[3]					Not for processing sweet corn.
Bravo Ultrex	M	14	0.7 to 1.8 lb	10.9 lb	There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Bravo WeatherStik	M	14	0.75 to 2 pt	12 pt	
Dexter Max	M/11	7	1.6 lb	24 lb	
Dexter XCEL	M/3/11	7/49	48 oz	240 oz	Re-entry interval 19 days for sweet corn.
Elatus	11/7	7	5 to 7.3 oz	2 apps	Apply before disease onset. Minimum 14 days between applications. No aerial application.
Copper, fixed coppers[5]	M				Leaf blights only. See label for rates.
Dithane M45 and mancozeb[3] generics	M	7	1.5 lb	12 lb	There are multiple Dithane formulations and mancozeb generics on the market. See label for rates.
Headline	11	7	6 to 12 fl oz	72 fl oz	Use lower rates for rust and gray leaf spot.
Headline SC	11	7	6 to 12 fl oz	72 fl oz	Apply before disease onset. Use lower rates for rust and gray leaf spot.
Headline AMP	11/3	7	10 to 14.4 fl oz	57.6 fl oz	
Miravis Neo	7/3/11	14	13.7 oz	3 apps	
Muscle ADV	M/3	14	1.1 to 1.6 pt	4 apps	Begin applications prior to disease development.
Priaxor	7/11	7	4 to 8 fl oz	16 fl oz	Apply prior to development of disease.
Quadris and azoxystrobin[4] generics	11	7	6 to 15.5 fl oz[4]	6 apps	Use lower rates for rust.
Quilt Xcel and propiconazole + azoxystrobin[3] generics	11/3	14	10.5 to 14 fl oz	56 fl oz	
Prosaro 421SC	3	7	6.5 fl oz	26 fl oz	
Stratego	11/3	14	10 fl oz	30 fl oz	
Stratego YLD	11/3	14	4 to 5 fl oz	20 fl oz	
Tilt and propiconazole[3] generics	3	14	2 to 4 fl oz	16 fl oz	Use higher rates for rust.
Toledo and tebuconazole[3] generics	3	7	4 to 6 fl oz	24 fl oz	
Vertisan	7	7	10 to 24 fl oz	48 fl oz	

1 Products with numerical FRAC codes must be alternated or tank-mixed with products that have a different FRAC code to discourage resistance development. See product label for maximum number of consecutive applications allowed. Refer to the table on pages 22-24 for more information on FRAC codes.
2 Pre-harvest interval.
3 Generic products available (Appendix F). Amounts and seasonal limits per acre are product dependent.
4 Use higher rate when pressure is severe.
5 Fixed coppers labeled in KY include: Badge SC, Badge X2, Basic Copper 53, Champ, Champ WG, ChampION++, C-O-C-S WDG, Cueva, Cuprofix, Cuproxat, Kentan, Kocide 2000, Kocide 3000, Kocide DF, KOP-5, MasterCop, Nordox 75 WG, Nu-Cop 30 HB, Nu-Cop 50DF, Phyton 35, and Previsto. Rates may vary by product and by crop. Refer to specific product label for this information.

Cucurbits (Vining Crops)

Cucumbers, Muskmelons, Squash, Pumpkins, and Watermelons Gourd family (Cucurbitaceae):
Cucumis sativus [cucumber]; Cucumis melo, Reticulatus Group [Muskmelon]; *Citrullus lanatus [Watermelon]*

Planting and Culture

Cucumber

Cucumbers are grown in Kentucky primarily for fresh market (slicing types) rather than for processing (pickling types). Planting and cultural requirements are similar for both. Cucumbers do best in firm, deep, well-prepared seedbeds. Fall plowing is recommended. The soil should be well drained and high in organic matter for best results. Apply 10 tons of manure per acre the previous fall if available. Land that has been in sod is very desirable. The soil should be disked two or three times in early spring to prepare for seeding. Disking helps to eliminate early germinating weed seeds and prepare a fine seedbed. A cultipacker will help prepare a good seedbed. Do not plant cucumbers on land that was treated the previous year with a triazine herbicide such as atrazine, metribuzin, or Karmex.

For hand-harvested pickling or slicing cucumbers, plants can be left to grow on the ground or be trellised. If not trellising, train vines to run lengthwise in the row soon after vining starts. Cultivating in one direction will also help to train plants to run in the row. This training will enable harvesters to pick more easily and quickly, and the plants will not be damaged as seriously. Cultivation should be shallow to prevent root damage. Trellising cucumbers can lead to improved fruit quality because the fruit is not touching the soil. It also helps prevent damage to the vines and more effective control of many diseases and pests (can have better coverage of pesticides, for example). Harvesting can be extended and be more thorough when cucumber vines are trellised because there can be fewer overly large cucumbers (jumbos) and fewer culls. It is easier to see ripe cucumbers on the trellis system compared to on the ground. However, trellising requires a greater investment than growing on the ground. There can be significant cost from erecting the trellis, the labor involved in maintaining plants on the trellis and pruning, and the clean-up at the end of the season. If trellising, place a post every 15 feet and train and prune plants frequently.

Start seed about the first of May in most areas of the state or when designated by the company with which you may be contracting. Continued plantings at one- or two-week intervals can be made to extend the harvest season (see Appendix K).

Slicing cucumbers are usually grown on black plastic with trickle irrigation to increase yields and earliness. Cucumbers can be direct-seeded through plastic mulch using seeders designed for that purpose, or they can be transplanted at about two to three weeks after seeding.

Muskmelon

Muskmelons (cantaloupes) and specialty melons are warm-season crops. They require a relatively long growing season of 80 to 100 days from seeding to marketable fruit. Well-drained, lighter-textured (sandy or sandy loam) soils are considered best for cantaloupes, although medium-textured soils can be just as productive with good management practices. Lighter-textured soils warm up faster than heavier soils. Because of potentially serious disease problems, melons are best grown on land that has not been in vine crops (cantaloupes, watermelons, squash, pumpkins, etc.) for at least three years.

The vining habit of the plant and its large leaves make it especially susceptible to wind damage. Planting cantaloupes between strips of annual rye or some similar, taller-growing plant will provide windbreak protection. In addition, growers can orient rows in the direction of prevailing winds (usually winds blow from the southwest in most parts of Kentucky) so that wind blows down rows rather than across them.

Cantaloupes can be direct-seeded to the field or grown as transplants in the greenhouse or hotbed and transplanted to the field. Generally, 2 pounds of seed is sufficient to direct-seed an acre; one quarter to one half of a pound per acre is sufficient for transplants. Plant the seed one-half to three-quarters of an inch deep after danger of frost is past (see Appendix K).

Transplants produce earlier ripening fruits that will often bring much higher early prices. With transplants, plant the seed three weeks before the plants are to be transplanted to the field. The plants should have two or three true leaves. Plant one or two 72-128 cell plug trays.

It is crucial that plants be protected from cucumber beetle feeding from the day of seedling emergence or from the day of transplanting to reduce the risk of bacterial wilt disease (vectored by the beetles). The insecticide imidacloprid has provided good early season systemic control of cucumber beetles on melons in Kentucky, reducing the potential for bacterial wilt while the plants are small. Although several soil application methods may be used with this product, the post-transplant drench is recommended for best control: a small amount of the imidacloprid solution is applied at the base of each plant immediately after transplanting. With proper calibration, this can be done quickly and accurately using a backpack sprayer with the nozzle removed (see the "Insect Control" table and current label for recommended rates). Imidacloprid should not be used in the setter tank water because of the potential for worker exposure during transplanting.

Specialty Melons

Specialty melons (honeydews, canary, galia, and others) are

excellent items for direct market sales; they are full flavored and far superior to what can be obtained through local supermarkets. These melons are more difficult to grow than cantaloupes and require an extended spray program in Kentucky. Specialty melons are highly susceptible to bacterial wilt, and post-transplant drench application of an imidacloprid insecticide (Admire, etc.—see the "Disease Control" and "Insect Control" tables) is an absolute necessity to achieve success. A season-long weekly preventative fungicide spray schedule for Anthracnose is also critical.

These melons do best when planted around May 1 and transplanted to the field around June 1. This allows harvest to coincide with dry weather late in the season, which increases flavor and sugar content. Specialty melons need slightly wider plant spacing; see "Plant Spacing" (page 64). Some specialty melons, especially galia melons, are prone to magnesium deficiencies, and preventive measures may be required (see page 65). In addition, growers will need to gain some experience with each type to determine exactly when to harvest, as many specialty melons do not "slip" or may not change color at maturity in the same way that muskmelons do. See descriptions in the "Varieties" table for specific harvesting guidelines.

Squash and Pumpkin

Squash and pumpkins produce best on well-drained, fertile soil. The plants produce large, shallow root systems very rapidly in the top 8 to 10 inches of soil, which should be prepared into a firm, well-fertilized seedbed. Squash and pumpkins do well in soils where 10 to 12 tons of well-rotted manure has been applied per acre. To help avoid soilborne disease problems, select fields that have not had other vine crops, tobacco, tomatoes, or peppers for at least three years. Calculate the number of days to harvest to determine when to plant pumpkins for Halloween (see Appendix K). Growers usually harvest pumpkins in mid-September to allow time for marketing.

Some Kentucky growers have successfully grown pumpkins using a no-till system by seeding into stubble of a rye or rye-vetch cover crop that has been killed with herbicide. Pumpkins can be direct-seeded into the mulch with a modified no-till corn planter. This practice can eliminate the need for washing pumpkins prior to marketing, may reduce fruit rots, and makes for an easier/cleaner field for schoolchildren or "pumpkin festival" customers to walk in. No-till has been successful on well-drained soils but may be problematic on heavier soils; problems with rodent feeding have been encountered by some growers using this system.

Having irrigation available for pumpkins will pay big yield and quality dividends in some years. A good irrigation system that can apply 1 to 2 inches of water a week and keep ground temperatures a little cooler will increase yields dramatically and pay for itself in a drought year. Using drip irrigation on pumpkins has made the difference between high profits and total crop failure for some Kentucky pumpkin growers in dry years; the easiest and most effective system employs 8- to 10-mil drip lines without the use of plastic mulch. Supplemental irrigation is critical in dry summers during flowering and fruit setting.

Summer squash (yellow straightnecks, yellow crooknecks, or zucchini types) are usually grown for an early summer market in mid- to late June or for an early fall market when prices begin to rise in September (see Appendix K). Growers producing squash for the late summer/early fall market usually encounter serious virus or fungal disease problems and should plant either a variety with the precocious yellow trait that masks virus symptoms or one of the varieties with conventional or genetically engineered virus resistance. Varieties are also available with resistance to powdery mildew (see "Varieties" table).

Squash and pumpkins are warm-season crops and do not do well until soil and air temperatures are above 60°F. Seed may decay before germinating if planted in cold, wet soil. Black plastic on raised beds with trickle irrigation will speed soil warming in spring squash plantings and can dramatically increase early and total yields. Use white plastic mulch for late squash plantings in July or August. Seed or transplants can be planted through the plastic by hand, with a waterwheel setter or with machinery designed for direct-seeding through plastic.

Squash or pumpkin transplants should be started in the greenhouse in 72-128 cell trays two to three weeks before the anticipated transplanting date. The plants are ready when the first true leaves are fully developed; delays in transplanting can result in stunting of plants in the field.

Watermelon

Lighter-textured soils are considered best for watermelons, although medium-textured soils can be just as productive with good management practices. Watermelons should not be grown on the same ground year after year because of disease problems; they are best grown on land that has not been in tomatoes, peppers, or another vine crop (cantaloupes, squash, pumpkins, etc.) for at least three years.

Watermelon seedlings are often transplanted to the field. This method must be used for seedless watermelons due to their high seed costs and poor germination percentages. If this procedure is followed, the seed should be planted 14 to 21 days before planting to the field (see Appendix K). Transplants should be planted to the field around the time the first true leaf forms. Transplanted melons will mature 10 to 14 days earlier than direct-seeded melons.

Black plastic on raised beds with drip irrigation is commonly used in commercial watermelon production for earlier maturity and higher yields; soils warm up faster in the spring, and weeds will not grow under the mulch. Soil moisture is also retained and nutrient leaching minimized.

Direct-seeding in hills was once the most common method of planting watermelons. The seedbed for planting should be thoroughly prepared to ensure good plant stands. Soil moisture should be adequate throughout the early growing season to produce good plant growth and vigorous blossoms. After fruits reach full size, it is usually best to withhold or reduce irrigation during the ripening season. Sugar content will usually be higher and the melons will have better flavor if moisture levels are not high during ripening. Keep in mind that watermelon plants have deep root systems.

Good weed control is essential for high-quality melons. Melon yields and sugar content can be reduced if weeds are allowed to shade and otherwise compete with the plants. Black plastic helps to control weeds during early growth; however, it is critical to control weeds in the bare ground middles between rows of plastic. Herbicides and/or mechanical cultivation can be effectively used for early-season weed control in these middles.

Special Considerations for Seedless (Triploid) Watermelon Production:

Germination

- The most common reasons for poor germination are overwatering, incorrect watering, poor temperature control, and shallow seed placement.
- For growing transplants, the growing media should be moist but not wet. Check moisture level by squeezing a handful of media. Generally, if water drips from the media, it is too wet.
- Water the media and allow it to dry for 12 to 24 hours. During this time, bring the temperature of the media to 85° to 90°F. Before filling trays and seeding, stir the media to ensure that it is evenly moistened.
- Seeds should be planted between ½ to ¾ inches deep in trays. This planting depth helps prevent germinating seeds from pushing out of the media and maintains better uniformity of moisture around seed.
- Plant seeds with the pointed end (root end) up; this helps prevent the seed coats from sticking to the germinating seedling.
- Place the seeded trays in a germination room or chamber for 48 to 72 hours or until germination begins. The temperature of the room should be held at 85° to 90°F and the relative humidity maintained between 90 and 100 percent.
- Once seedlings have begun to emerge, move trays to the greenhouse. Maintain a temperature of approximately 80° to 85°F until germination is complete.
- During the first week in the greenhouse, water only as needed to keep the planting media moist. Do not overwater, as this may destroy ungerminated seeds.
- Once the seedlings are established, temperature and watering can be adjusted to achieve sturdy plants.

Transplanting and Pollination of Seedless Watermelons

- A pollenizer, which can be a traditional seeded variety or a special pollenizer melon must be present for pollination and fruit set. Good pollination is extremely important for seedless watermelon production. Inadequate pollination results in triangular-shaped fruit, lower quality, and increased incidence of hollow heart.
- A ratio of 2 to 3 seedless plants to one seeded (used as pollenizer) is recommended. Pollenizer varieties can be planted on the edge of beds between the third and fourth seedless plant. When using a seeded melon as a pollenizer which will be harvested, outside rows and every third row in the field should be planted with the seeded variety. Never plant seedless and seeded (pollenizer) varieties in separate adjacent blocks in the field.
- Specific pollenizer varieties generally flower earlier and longer than typical seeded melons. When using a seeded melon as the pollenizer use a main-season variety. Early or late varieties may not provide pollen during the entire season, thus reducing fruit set.
- Specific pollenizer melons will be easily distinguished from your crop. Pollenizer varieties will produce small softball-size melons that are not harvested and easily crushed in the field. When using a diploid (seeded) variety as a pollenizer be sure that it distinguished by shape or color from the seedless melons at harvest and one that is marketable, as it will make up about one third of your total production.
- Specific pollenizer varieties generally flower earlier than the seedless melons they are planted with. However, when using a traditional seeded melon as a pollenizer it should be seeded in the greenhouse one to two weeks earlier than the seedless variety. This schedule ensures good pollination when the seedless variety begins to produce female flowers.

Black Plastic and Irrigation

Black plastic mulch on raised beds with drip irrigation is often used to obtain higher yields and to encourage faster growth and earlier maturity. Drip irrigation increases fruit quality and quantity and allows fertilizer to be injected through the system (fertigation). Plastic mulch can be purchased in roll widths of 3 and 4 feet; the 4-foot-wide film is most suitable for melons.

Bed shapers/plastic mulch layers and waterwheel setters are commercially available to make raised beds, lay plastic and drip lines, and aid in transplanting. A fine seedbed is required for plastic laying by machine; this operation is nearly impossible on cloddy ground. Clods will puncture plastic mulch, making it more vulnerable to wind damage. Machines are also available that enable direct-seeding through plastic mulch.

Plant Spacing

Growers should also plan for spraying, harvesting, and other field operations by leaving an 8- to 9-foot-wide middle, or "skip row,"

after every fourth to sixth bed. The number and placement of these skip rows will depend on the type of sprayer being used.

Cucumbers

Pickling cucumbers are usually machine harvested. If a crop is to be grown for mechanical harvest (once-over harvest), seeding with precision seeders in rows 15 inches apart with seed 2 to 3 inches apart in the row is recommended. Four pounds of seed per acre is required at this close spacing. For hand-harvested pickling or slicing cucumbers grown on bare ground, space rows 4 to 4 ½ feet apart and plant three to four seeds per foot of row. Thin plants to 8 inches between plants in the row. The seed should be planted ¾ to 1 inch deep. Uniform depth of planting is important to get uniform plant growth and maturity. Two pounds of seed will be required per acre. Plasticulture cucumbers are usually grown in double rows with 12 to 18 inches between the two rows and 9 to 12 inches between plants within each row. Beds are usually spaced 5 feet between centers. Only a single plant should be grown in each planting hole.

Muskmelons or Specialty Melons

On plastic, single plants are usually spaced 18 inches apart in the rows on plastic; some growers use two plants per hill spaced 3 feet apart in the row. For direct-seeding in bare ground or into plastic mulch, rows should be 5 to 6 feet apart, with plants thinned to hills 2 to 3 feet apart in the row and two or three plants per hill. Plant specialty melons 3 feet apart in the row with rows 5 to 6 feet apart on black plastic with drip irrigation and fertigation.

Summer Squash

On plastic, single plants are usually transplanted 18 inches apart on beds 5 to 6 feet apart. For direct-seeding in bare ground or into plastic mulch, plant two to three seeds every 18 to 24 inches apart in rows 4 to 6 feet apart. Seed should be planted 1 inch deep.

Pumpkins and Winter Squash

Final plant stands for extra large varieties should be 3 to 4 feet apart in the row with rows 8 to 12 feet apart (24 to 48 square feet per plant). Smaller bush types are spaced 2 to 3 feet apart in the row, with rows 5 to 6 feet apart. Miniature pumpkins can be planted as densely as 1 to 2 feet apart in the row with rows 4 to 6 feet apart. Pumpkins can be transplanted or direct-seeded at the above spacings. Seeds are planted at a depth of 1 to 2 inches. Many seed companies publish charts for appropriate plant spacing for the varieties that they sell.

Watermelon

Spacing on plastic with drip irrigation depends on the variety and the desired melon size. In general, 6 to 8 feet between-row spacings and 3 to 4 feet in-row spacings are used. Use wider spacings to produce larger, heavier melons. Smaller "icebox" watermelons can be spaced more closely with in-row spacings of 2 feet and between-row spacings of 5 to 6 feet. Mini-seedless (also called "palm" or "personal") watermelons are spaced 1 ½ feet apart within rows and 5 to 6 feet between rows to produce the greatest number of melons weighing less than 8 pounds. On bare ground without irrigation, each plant requires about 48 square feet of space for maximum yield of larger-sized melons. In this case, thin plants to about 4 feet apart in the rows with rows spaced 12 feet apart.

Fertilizing

Cucumber

Make fertilizer and lime applications based on soil test results. A soil pH of 6.5 to 6.7 is most desirable for cucumbers. All fertilizer should be broadcast and disked in well before planting. All phosphorus and potassium and a portion of the total nitrogen requirement should be applied before laying plastic when plastic mulch and drip irrigation are used. The remaining N requirement can be fertigated (see "Fertigation" table). When lime is needed before growing cucumbers, apply a dolomitic liming material if available in your area.

Muskmelons

Phosphorus, potassium, and lime applications should be based on soil test results. Maintain the soil pH between 6.5 and 7.0; liming will be necessary if pH falls below 6.5. Because of shallower rooting depth and preplant N applications, muskmelons grown with drip irrigation on plastic mulch may be more susceptible to magnesium deficiency if soil pH is less than 6.5. Preplant and fertigated magnesium applications may be required on low CEC soils; added magnesium may also increase melon sugar contents. See below and Appendix B for further discussion of magnesium and molybdenum deficiencies and recommended application rates.

With plastic mulch and drip irrigation, apply all the lime, P and K and ½ of the total N recommendation before laying plastic. The remaining nitrogen can be divided into equal weekly doses and fertigated as indicated in the "Fertigation" table.

Magnesium deficiencies. Muskmelons have high magnesium requirements. Deficiencies sometimes appear a few weeks before harvest when fruits are rapidly growing in size and weight and when fruit loads are heavy. Typical symptoms are yellowing between the veins (veins remain green) on the oldest leaves (those nearest the crown of the plant). This interveinal discoloration turns brown or tan over time and eventually results in much of the leaf tissue dropping out, leaving a green and white leaf "skeleton." Entire fields are defoliated in severe cases. Magnesium deficiency problems are more likely to occur on light, sandstone-derived soils and in very dry years. Frequent fertigations with calcium or potassium nitrate can make the problem worse by competing with and displacing magnesium in soils. Preventive and/or corrective measures are required, especially on low CEC soils.

In general, we would like to have about 200 pounds per acre of magnesium on soil tests prior to

planting. Magnesium sources include dolomitic lime (12% Mg), epsom salts (= magnesium sulfate, 10 to 16% Mg), magnesium nitrate (6.3% Mg), and magnesium oxide (45 to 55% Mg). Epsom salts and magnesium oxide can be fertigated through the drip system; make weekly applications of 1 to 2 pounds actual magnesium per acre (10 to 20 pounds per acre epsom salts or 2 to 4 pounds per acre magnesium oxide). Application rates may vary with solubility of the materials (check with the manufacturer). Foliar applications of epsom salts are usually not as effective. A better long-term solution is to raise soil test magnesium levels with dolomitic lime prior to planting, although some soils may also require magnesium fertigations throughout the season.

Molybdenum deficiency is usually associated with acid soils. Molybdenum becomes less available to the plant as the pH is lowered. Under lowered pH, manganese and aluminum toxicities may also occur and reduce yields. First symptoms are light yellow spots on the leaves followed by death of the tissue at the margins. Symptoms have also been observed in cantaloupe where black plastic has been used and the preplant nitrogen has not been disked in deep enough. This can result in lowered pH in the top 2 to 3 inches of soil where most of the plant roots are concentrated. Soils should be tested and limed to maintain pH around 6.5 to 7.0. A foliar spray of sodium molybdate usually corrects molybdenum deficiency within two weeks. Apply 1 quart of setter water molybdenum per acre as a foliar spray. This product contains 3.5 ounces actual molybdenum per gallon. Apply no more than 12 ounces actual molybdenum during a five-year period on the same field.

Pumpkins and Squash

Pumpkins and squash can tolerate a fairly broad range in soil pH from 5.5 to 6.8. Apply lime if needed to raise the pH to 6.5. Apply phosphate and potash as required based on soil test results. Potassium and especially phosphorus are likely to accumulate in most Kentucky soils following several years of heavy applications for vegetable crops or tobacco.

Consider the previous crop when deciding how much nitrogen to apply; there will probably be some residual nitrogen following a crop that received heavy doses of nitrogen fertilizer during the previous season. Apply 30 to 50 pounds of nitrogen per acre prior to planting crops to be grown on plastic with drip irrigation. See the "Fertilizer" table for rates for bare ground plantings.

The recommendations in the "Fertigation" table have worked well for growers in Kentucky for summer squash grown on black plastic mulch with drip irrigation. Fertigation should begin about two weeks after transplanting and continue throughout the season. A grower may need to modify the recommendations slightly, depending on duration of harvest, soil type, previous crop, etc.

Calcium nitrate and potassium nitrate are commonly used water-soluble sources of nitrogen for fertigation. The simplest system that has worked well on medium-textured soils in Kentucky uses calcium nitrate or potassium nitrate injected into the drip irrigation water. We recommend that all potassium and phosphorus be applied prior to laying plastic. In areas with very sandy soils, there may be some yield advantage in fertigating some of the potassium. In these cases potassium can be fertigated with a water-soluble muriate of potash (0-0-60) or potassium nitrate (14-0-45).

Watermelons

The soil pH should be maintained between 6.0 and 6.5. Liming will be necessary when the pH is below 6.0. Fertilizer and lime applications should be based on soil test results. With plastic mulch and drip irrigation, apply all the P and K and ½ of the total N recommendation before laying plastic. The remaining nitrogen can be applied in equal weekly doses according to the "Fertigation" table.

Pollination

Cucumber

Provide one hive of bees for each acre of cucumbers to ensure good pollination. This is especially important for high plant populations of gynoecious hybrid varieties grown for once-over mechanical harvesting. Low bee populations result in low fruit set and poor fruit shape.

Muskmelons

Muskmelon have both male and perfect flowers on the same plant. However, the perfect flowers are not capable of self-pollination and must receive pollen from male flowers. Growers with large acreages should provide one to two strong hives of bees for each acre of plants to ensure good pollination. Spraying for insect control should be done late in the day to avoid unnecessary bee kill.

Pumpkins and Squash

The plants have separate male and female flowers on the same plant. Pollen must be transferred from the male flowers to the female flowers by bees in order to get high yields of good quality fruit. If bees are not abundant in the field at flowering time, hives should be placed near the field (but protected from potential spray drift), with at least one strong hive per acre. Special precautions should be taken with insecticide treatments during flower blooming; applications should be delayed until late in the afternoon to prevent killing pollinators.

Some varieties of pumpkins grown under high temperatures (90°F days and 70°F nights) produce female flowers that wither and die before they open. The same thing may happen if pumpkin plants are heavily shaded. In both situations, male flowers develop normally and open on schedule, but few if any female flowers are seen in the field. In some cases female flowers appear but fail to bear fruit because of pollen sterility at high temperatures. The variety 'Howden's Field' is particularly susceptible to these problems.

Watermelons

The plants have male and female flowers that grow separately on

the same plant. Bees must carry pollen from male flower to female flower to ensure good fruit set and development. Wild bees will help provide pollination; however, commercial growers should consider putting bee hives near their fields, but in areas protected from spray drift. One strong hive of bees is generally considered adequate for two acres of watermelons.

Harvesting and Handling

Cucumbers

Picking the first cucumbers that develop when they reach the proper size is very important. If the early crown set is not harvested, production will be greatly reduced. Cucumbers picked by hand should be harvested every other day for best yields and quality. Cucumbers should be handled carefully to prevent bruising and spoilage, especially slicing types sold for fresh market. Cucumbers should never be put in plastic bags or containers where air will be excluded for any period of time. Cucumbers for the fresh, wholesale market are waxed and marketed in 1 ⅑ bushel waxed cartons. Fancy cucumbers should be 2 ⅜ inches in diameter and 6 inches in length. Cucumbers can be held in storage for about two weeks at 45° to 50°F and a relative humidity of 95 percent. Do not store at temperatures below 45°F or chilling injury will result.

Muskmelons

Cantaloupes to be sold locally should be harvested at the full slip stage. The term "full slip" indicates that the vine easily detaches, or slips, from the fruit with a gentle pull. The ground color under the netting starts to turn yellowish at this time. For melons to be shipped and held for some time before marketing, it may be necessary to harvest at "¼ slip" to "half slip" (only ¼ to ½ of the end of the vine detaches from the fruit when gently pulled). In some cases it may be desirable to harvest melons based on subtle color changes in the fruit; check with buyers or co-op managers to determine exactly when to harvest. It may also be necessary to harvest every day or every other day during periods of high temperatures. Honeydew melons do not slip from the stem when ripe, but they do change colors. They usually take on a yellowish-white color and give off a slight aroma when ripe.

Harvest melons in the early morning while the fruit is cool. Care should be taken when walking through the plants to avoid injury to the plants. The plants can be trained during the early stages of development to grow in rows, enabling easier harvest. Temperature of the melon fruit at harvest may be 85° to 95°F or even higher. Cantaloupes benefit greatly from pre-cooling as soon after harvest as possible. Some chain store buyers may purchase only pre-cooled melons. Hydrocooling cantaloupes to a temperature of 55°F is possible. They should be kept at a relative humidity of 95 percent. Grower-shippers have been using forced air cooling at 40° to 42°F in recent years in order to participate in the larger chain store markets.

Summer Squash

Harvest at the proper size for your market and before the skin becomes tough and hard. The skin should still have a glossy appearance and will be ready for harvest from two to five days after flowers have fully opened. It is a good idea for squash pickers to use plastic buckets and wear soft gloves to avoid bruises, scratches, and fingernail punctures. Squash should be cut from the plant, leaving ½ to 1 inch of the stem attached to the fruit. Harvests may be required every other day or even daily during the peak. Always remove over-mature or oversized fruit from the plants to maintain plant vigor and production.

Summer squash is normally sold on the fresh, wholesale market in half-bushel (21 pounds) waxed cardboard cartons or 11/9 (42 to 44 pounds) bushel cartons or wire-bound crates. Produce buyers expect a uniform count of clean fruit in each carton or crate. Squash should be uniform in size to meet the buyer's count and weight requirements; talk to your buyers to become familiar with their requirements before packing the product. The USDA's Agricultural Marketing Service has established grading standards for squash and other vegetables. They are available on the Internet at ams.usda.gov/AMSv1.0/freshmarketvegetablestandards. Squash should be marketed quickly and not stored if possible; if storage is necessary, however, they can be kept for a week at 45° to 50°F and 90 to 95 percent relative humidity. Chilling injury can occur after several days of storage below 50°F.

Pumpkins

They are normally harvested when they reach a deep solid color and the rind is hard. Wholesale buyers may require a large percentage of 15-pound pumpkins and may also specify the number of pumpkins, or "count," per bin. Pumpkins that are picked when they are green and immature will not color up. In emergencies—late maturity, fruit rots occurring, or large insect populations present—it is possible to harvest pumpkins at the mature-green stage, and most of them will color up within a few weeks. At the mature-green stage, the skin has toughened up and cannot be punctured with your fingernail. It is recommended, however, that pumpkins undergo at least some change in color before harvesting.

Cut pumpkins from vines carefully, leaving a 3- to 4-inch stem attached. Pumpkins do not all mature at the same time on the plant but will continue to color up over a period of three to four weeks if diseases and insects are held in check. Sunny weather is especially important in the development of mature fruit with good color.

When harvesting, use a pair of loppers, pruning shears, or a sharp knife to snip the large stem from the plant; this makes for a more attractive stem and also prevents the stem from separating from the fruit. Pumpkins are best harvested when the rind is hard and has good color characteristics typical of the variety. Do not carry a pumpkin by its stem or "handle" since these often break off, reducing the pumpkin's

marketability and its storage life by encouraging decay.

It may be necessary to harvest and hold pumpkins in storage for two to four weeks before they are sold. Do not store on bare ground after harvest. Tobacco barns are usually a good place for storage. Spread out a layer of dry straw or hay and set the pumpkins on it. Keep them dry. Good air circulation will help reduce rotting. Pumpkins should be harvested and stored before temperatures drop to the 30s and 40s.

Although harvests for Halloween usually begin in late September to early October, high temperatures may cause pumpkins to mature in late August and early September. These pumpkins often rot or decay long before they can be marketed. Some rot, caused by injury or seasonal stresses such as drought and/or heat, is unavoidable. Diseases such as powdery or downy mildew, viruses, or gummy stem blight may also cause premature ripening. There are a few precautions that should be taken to minimize the decay of prematurely ripened fruit. Harvest should begin earlier. Get the pumpkins out of the field when they mature early. Pumpkins should be handled carefully to avoid cuts and bruises, which are the major entry points for rotting fungi and bacteria.

A curing period of seven to 10 days at temperatures of 80° to 85°F with relative humidity of 80 to 85 percent has been recommended in the past to heal over surface injuries and allow for further ripening; however, this practice is seldom used, and research has shown that it may not be necessary. It has not been beneficial for several types of squash, including Butternut, and may be detrimental to Acorn squash.

Store pumpkins cool and dry; storage temperatures should be 50° to 55°F with a relative humidity of 50 to 70 percent. The surface of the fruit should be dry. Keep the area as well ventilated as possible and away from any ethylene sources (tomatoes, apples). Ventilation can be provided by placing fruits on pallets or slatted benches, which allow air movement around the fruits. Avoid stacking pumpkins on top of one another. Stacking is a sure way to create bruises, and the pile will only create unwanted heat. It is possible to hold pumpkins for six to eight weeks when held at 50° to 55°F but only for a few weeks at 70°F.

Ornamental pumpkins have virtually no value after Halloween. Plant early enough for the variety you have selected and be careful not to over-fertilize with nitrogen, which can delay maturity. A dry period without irrigation can also result in pumpkins at the wrong stage of maturity at harvest. Green-mature pumpkins can be harvested but are not as likely to color up uniformly.

Avoid temperatures below 50°F, which can cause chilling injury to green-mature pumpkins and will result in poor color and more fruit decay. One possibility is to put green or partially colored pumpkins in a warm greenhouse, which will accelerate the maturing process.

Irrigation and proper post-harvest care are always good investments, especially because supplies may be short after growing seasons that result in orange pumpkins in August or green pumpkins in September.

Pumpkin prices and, therefore, returns per acre, can vary greatly depending on supplies available and the marketing channel used. Higher and more stable prices can be expected from direct sales or even "pumpkin festival" sales, but this market can become saturated with too many growers near a population center. In some cases, smaller growers can help supply the larger festival market grower to obtain prices that may be higher than wholesale. Larger producers and those who do not have time for direct sales will need to find wholesale buyers or, in some cases, sell directly to supermarkets. Wholesale prices are often considerably lower than direct market (retail) prices. Smaller growers should consider joint marketing efforts to attract wholesale buyers. Although consumer demand for pumpkins has expanded considerably in recent years, more growers are getting into production, and some markets may disappear at harvest time. Good production, management, and marketing can result in high profits, especially when supplies are short.

Watermelon

A grower must become familiar with the variety to determine the best stage for harvesting. A dead tendril or curl at the point where the fruit attaches to the vine is not a conclusive indication that the fruit is ready for harvest. "Thumping" the fruit is sometimes used, but only over-ripeness can be determined in this manner.

The best indicator for harvest is the color of the underside of the melon. When 'Crimson Sweet' melons turn yellowish-brown on the bottom surface, for example, they are fully ripe and ready for harvest. The fruits will take on a dull appearance compared to their slick appearance prior to maturity. Determining the proper time to harvest seedless watermelons is generally more difficult than for seeded melons. The death of a tendril usually does not correlate with seedless watermelon ripeness. Melon undercolor is usually the only index of maturity on seedless watermelons, and this color will vary among varieties. Melons should not be left long in the sun, or they may develop sunscald.

Melons should be handled gently to avoid bruising. When loading, melons should not be stacked so high that their weight bruises the bottom fruit. Watermelons should be stored at 50° to 60°F and 90 percent relative humidity.

VARIETIES: Cucumbers

Variety	DTM[1]	Comments
SLICING		
Intimidator	53	Early-maturing, CMV, scab, and angular leaf spot, Good for early and late production, smooth fruit, gynoecious.
Bristol	54	Highly productive, resistance to Anthracnose, angular leaf spot, CMV, scab and zucchini yellow mosaic virus; intermediate resistance to downy mildew and papaya ringspot virus, gynoecious.
Mamba	54	Sets fruit well, resistance to scab; intermediate resistance to Anthracnose, angular leaf spot, CMV, powdery mildew, downy mildew, papaya ringspot virus, watermelon mosaic virus and zucchini yellow mosaic virus.
Speedway	56	Early variety with CMV, powdery mildew, scab, Anthracnose, and angular leaf spot tolerance, gynoecious.
Python	55	Early, very productive, dark green, CMV, scab, Anthracnose, angular and target leaf spot, powdery mildew, gynoecious.
Tasty Green	62	8-10" long slender fruit. Good flavor, similar to a greenhouse burpless cucumber, does well in high tunnels with pollination. For local market, not recommended for wholesale production. Resistant to Anthracnose, angular leaf spot, powdery mildew, downy mildew, CMV scab; monoecious.
Marketmore 76 (open-pollinated)	67	8-9" slender fruit. Scab, powdery mildew, and CMV resistant. For local market, not for commercial production. Monoecious, open-pollinated.
PICKLING		
Calypso	52	1" diameter fruit. Resistant to scab, Anthracnose, powdery mildew, and CMV. Hybrid, gynoecious.

VARIETIES: Melons

Variety	DTM[1]	Use	Quality[3]	Comments
EASTERN CANTALOUPE				
Minerva	77	Local, shipping	E	7 to 8 lb round to oblong with deeper sutures than Athena and heavy netting. Resistance to powdery mildew and *Fusarium* races 0, 1 and 2.
Athena	78	Local, shipping	E	Market standard, 5 to 7 lb melon; sutureless and fine heavy netting, small cavity, firm flesh, resistance to powdery mildew and *Fusarium* races 0, 1 and 2. Looks like a large Western melon.
Aphrodite	80	Local, shipping	E	6 to 8 lb; earlier, larger Athena type, resistance to powdery mildew 1, 2 and *Fusarium* race 0, 1, 2.
Wrangler	80-85	Local	E	4 to 5 lb small Tuscan type cantaloupe with dark green sutures, medium net, excellent flavor.*Fusarium* race 0, 1, 2, and powdery mildew resistance.
Atlantis	82	Local, limited shipping	E	6 to 8 lb Eastern type with refined netting, shallow sutures, high sugar, smooth firm deep orange flesh. Powdery mildew race 1, 2 and *Fusarium* race 1, 2 resistance.
Orange Sherbet	83	Local, shipping	E	6 to 8 lb; very large Tuscan type, oval, densely-netted with shallow sutures, high sugar content. Resistance to powdery mildew race 2 and *Fusarium* race 1, 2.
Tirreno	83	Local	E	2-3 lb netted Tuscan type with deep sutures. Resistance to powdery mildew 1, 2, and 5, *Fusarium* race 1, 2..
SPECIALTY MELONS[2]				
Honey Orange	75	Local	VG	3-4 lb honeydew, cream colored exterior, orange flesh, very sweet.
Arava	77	Local	VG	4 lb galia melon, netted exterior, sweet green flesh, excellent flavor, harvest when just turning yellow, relatively short shelf life. Intermediate resistance to powdery mildew.
San Juan	78	Local	VG	3-5 lb honeydew, pale green flesh, excellent flavor. Resistant to *Fusarium* 0-2, powdery mildew 1,2.
Sensation	80	Local	O	5 to 6 lb gourmet melon, round, medium netted light yellow rind, creamy white interior, harvest when rind begins to turn yellow. Resistant to powdery mildew and *Fusarium* wilt 0-2.
Pixie	80	Local	E	2-3 lb muskmelon X galia melon cross; very firm, very sweet, orange flesh; harvest when rind develops a yellow background.
Tasty Bites	75-80	Local	E	1-2 lb charentais X ananas cross, fully netted cantaloupe exterior, orange crunchy flesh with a nice after taste, harvest at slip. Resistant to *Fusarium* 1-2 and powdery mildew.
Summer Dew	88	Local	E	4 to 6 lb honeydew, green flesh, excellent flavor. Resistant to *Fusarium* 0, 2 and powdery mildew 1, 2.

1 Day to maturity
2All specialty melons in this category are highly susceptible to bacterial wilt; post-transplant drench applications of Admire insecticide together with a good preventative spray program for Anthracnose control are highly recommended.
3VG: Very Good; E: Excellent; O: Outstanding.

VARIETIES: Squash, Pumpkins, Gourds

Variety	DTM	Comments
SQUASH		
Straightneck		
Fortune	39	Precocious yellow trait (py) masks virus symptoms on fruit, downy mildew tolerant; teardrop shape.
Multipik	40	Precocious yellow trait (py) masks virus symptoms on fruit; downy mildew tolerant; teardrop shape.
XPT 1832 III	42	Precocious yellow trait (py) masks virus symptoms on fruit. Genetically engineered resistance to for CMV, WMV, ZYMV.
Conqueror III	41	Genetically engineered resistance to CMV, WMV, ZYMV and intermediate resistance to PRSV.
Lioness	50	G Tolerance to ZYMV, CMV, WMV, PRSV.
Zephyr	54	Bi-color with green blossom end, firm texture; variability in the amount of green on the blossom end
Crookneck		
Prelude II	40	Genetically engineered resistance to 2 viruses (WMV, ZYMV) plus conventional powdery mildew resistance. Full crook.
Destiny III	40	Genetically engineered resistance to 3 viruses (WMV, CMV, ZYMV); similar to Dixie. Semi- to full crook.
Gentry	43	Semi-crook; reduced spines, green stems; open bush plant.
Gold Star	50	Semi-crook; smooth, glossy, uniform shape; intermediate resistance to CMV and powdery mildew.
Zucchini		
Spineless Perfection	44	Spineless, intermediate resistance to downy mildew, WMV and ZYMV.
Green Machine	44	Medium green color with light speckles, cylindrical fruit; intermediate resistance to downy mildew, CMV, WMV and ZYMV.
Tigress	45	Cylindrical, slightly tapered; attractive medium to dark green; tolerant to WMV, ZYMV.
Zucchini Elite	45	Long, slightly curved and tapered fruits.
Cashflow	45	Medium green fruit with a slight taper, tolerant to some races of ZYMV, large plant.
Payroll	45	Reduced spines, attractive medium green fruit; intermediate resistance to downy mildew, WMV and ZYMV.
Other Summer Squashes		
Papaya Pear	45	Yellow pear shaped squash, 3.5 inches, AAS winner
Sunburst	50	Bright yellow scalloped, AAS winner.
Patty Pan	54	White scalloped; plants compact bush type.
Acorn		
Autumn Delight	70	1.5 lb, high yields, uniform appearance, intermediate resistance to powdery mildew.
Tay Belle PM	70	1 to 1.5 lb, powdery mildew tolerant, attractive, dark green exterior, bush type plant, medium orange sweet, tender flesh; excellent taste.
Honey Bear	85	1 to 1.25 lb fruit, excellent taste, intermediate resistance to powdery mildew, AAS winner.
Cream of the Crop	85	1.5 lb, attractive creamy white exterior, cream colored flesh, bush type plant.
Table Ace	85	1.5 lb, dark green exterior, yellow orange flesh, semi-bush plants hold up well, high yielding.
Table Gold	95	1 to 1.5 lb, bright golden exterior, dark orange flesh, semi-bush plant, very attractive and excellent taste.
Ornamental Acorn		
Carnival	85	1 to 1.5 lb, skin flecked with shades of green, gold, and yellow, semi-bush plant.
Heart of Gold	90	1.5 lb, white with dark green mottling and golden flesh, large vine, excellent taste.
Celebration	100	1 lb, cream colored with orange stripes and flecks of green, high sugar content, large vine; intermediate resistance to powdery mildew.
Butternut		
Butterboy	80	Very uniform, and early, slightly smaller than others, compact vine.
Chieftain	80	2 to 2.5 lb, bush type plant; powdery mildew resistance.
Polaris	100	3-4 lb, uniform size an shape, cracking tolerance, large vine.
Waltham Butternut	110	3 to 5 lb; blocky and uniform, large vine.
Buttercup/Kabocha		
Sun Spot	75	2 lb; very attractive, orange fruit with dark orange, fine grained, slightly moist, sweet flesh (buttercup).

(continued on next page)

VARIETIES: Squash, Pumpkins, Gourds *(continued)*

Variety	DTM[1]	Comments
Sweet Mama	85	5 lb; sweet, fine-grained, deep yellow flesh, dark green fruit; excellent taste and high yielding (kabocha).
Delica	90	4 lb; medium-dry, slightly sweet flesh; dark green with gray-green stripes; excellent taste (kabocha)
Special Export	90-95	3 lb; excellent flavor, attractive exterior and interior, excellent eating quality (kabocha).
Burgess Buttercup	90	2 lb; smooth texture; excellent eating quality.
Sunshine	95	4 lb; bright orange skin, nutty, smooth, stringless; very sweet, excellent eating quality (buttercup).
Spaghetti		
Small Wonder	70	2 to 2.5 lb; yellow exterior; large vine
Vegetable Spaghetti	100-105	Large 4 lb fruit, vigorous vine.
Miscellaneous Squash		
La Estrella	70-90	10 lb, Calabash squash, attractive green to tan blotchy exterior, fluorescent orange, moist fine grained flesh.
Bush Delicata	100	1 lb, exterior creamy white with green stripes, powdery mildew tolerance, excellent quality.
Grey Ghost	100	7 lb, attractive grey exterior, yellow orange, moist fine grained flesh, storage squash with ornamental value.
Cushaw Green Stripe	110	15 lb, very productive.
PUMPKINS		
Extra Large		
Atlantic Giant	120	Pink-orange color, world record over 1,000 lb.
Prizewinner	120	50 to 200 lb, orange, attractive; very large with good shape and color for extra large pumpkins, limit to 1 fruit per vine to get maximum size.
Full Moon	120	White color, 60 to 90 lb fruit, 36 x 24 inches.
Large (15-35 lb)		
New Moon	90	30 to 35 lb, white fruit, full vine, heavy fruit, good med-large white pumpkin.
Kratos	100	20-30 lb, round to round-flat, deep ribs, large thick handle, vigorous semi-vine growth habit, intermediate resistance to powdery mildew.
Mustang	100	15 to 18 lb, 10 x 12 inches, excellent powdery mildew resistance, strong handle, light orange color.
Apollo	110	18-32 lb, round to tall, dark orange, medium ribbing, good stem attachment, intermediate powdery mildew resistance.
Autumn Buckskin	110	12 to 18 lb, 7x10 inches, attractive, looks like a large buff colored acorn, large vine, pretty not a jack-o-lantern.
Cronus	115	25-50 lb, dark orange, well-defined ribs, large firmly-attached stem, large vigorous vine, intermediate powdery mildew resistance, high yield. Plant by May 25 to avoid heat and fruit set problems.
Aladdin	115	25 lb, deep orange, good yield potential, nice stems.
Magic Wand	115	15 to 25 lb, dark orange, similar to Magic Lantern with improved handles and a higher powdery mildew tolerance.
Gladiator	115	18 to 28 lb, deep orange, good handles and excellent powdery mildew tolerance, one of the best, good for roadside sales.
Magic Lantern	115	15 to 22 lb, dark orange, large vines, strong, dark green handle, powdery mildew tolerant.
Wolf	120	15 to 20 pound, full aggressive vines, unusually large stems, for roadside sales.
Medium (5-10 lb)		
Magician	90	10 to 15 lb, dark orange, round to tall, powdery mildew tolerant.
Hybrid Pam	90	5 to 7 lb, deep orange.
Cotton Candy	105	6 to 10 lb, white pumpkin, full vine
Lumina	110	7 to 8 lb white pie pumpkin for carving and painting with bright orange flesh; 9-inch diameter. Shape varies from globe to flat globe; not a particularly high yielder and fruit scars easily. Harvest slightly immature to obtain a better white color, otherwise these can turn gray.
Miniature (5 oz-4 lb)		
Casperita	77	½-1 lb, white deeply ribbed fruit; 3 inch diameter, edible and ornamental, semi-bush, intermediate resistance to powdery mildew
Cannon Ball	90	3 to 5 lb, orange to dark orange, round, smooth, long shelf life, solid pumpkin, powdery mildew tolerant.

(continued on next page)

VARIETIES: Squash, Pumpkins, Gourds *(continued)*

Variety	DTM[1]	Comments
Baby Boo	95	5 oz. white deeply ribbed fruit; 3.5 inch diameter, vines large; very productive.
Touch of Autumn	95	3.5 to 4 lb, 6 x 5 inches, very attractive, semi-bush vine type, excellent handles that remain dark green, stores well, powdery mildew tolerant.
Rockafellow	95	Pie type. 2.5 to 3.5 lb, bottom heavy and tall with long handle, powdery mildew tolerant.
Baby Bear	105	Pie type. 1.5 lb, 5 inch diameter, good disease tolerance.
Iron Man	110	3 to 4 lb, 7 to 8 inch diameter, dark orange; long shelf life; hard shell variety that is good for painting; tolerant to powdery mildew.
Lil' Ironsides	115	2 lb, 6 inch diameter, tough, hard, dark orange shell that is not able to be carved, strong stem, large vine, long shelf life.
Jack Sprat	100	Pie type. 2-3 lb, 5 x 6 inches, moderately long vines, medium length stems, uniform dark orange fruit color, delicious savory flavor. Powdery mildew resistance.
Little Giant	105	Pie type. 2-4 lb, 5 x 5 inches, attractive uniform fruit shape and color, attractive stems. Tender, sweet, full-flavored flesh. Most fruit near the plant base. Intermediate resistance to powdery mildew.
ORNAMENTAL GOURDS		
Autumn Wings Large Swan	100	Unique gourd, multiple colors with wings, warts, shaped like a swan gourd.
Autumn Wings Medium	100	Unique gourd, many colors with wings, shape of a spoon gourd.
Autumn Wings Small	100	Unique gourd, many colors with wings, shaped like a swan pear gourd. Potential for shipping.

VARIETIES: Watermelon

Variety	DTM	Size (lb)	Comments[2]
SEEDED			
Tiger Baby	80	10-12	Excellent quality, firm flesh, small seeds; resistant to *Fusarium* race 1.
Sangria	83	20-25	Crimson Sweet rind; elongated; outstanding flavor; fruit blossom end may taper with drought; tolerant to *Fusarium* race 1 and Anthracnose
Estrella	84	20-24	Allsweet rind type, long blocky fruit, bright red flesh, excellent flavor and texture; Intermediated resistance to Anthracnose 1 and *Fusarium* race 1.
Crimson Sweet	85	15-25	Dark and light green striped, blocky fruit; bright red tender sweet flesh; tolerant to *Fusarium* and Anthracnose.
Starbrite	85	21-29	Royal Sweet rind; elongated; very sweet and high yielding; resistant to *Fusarium* race 1 and Anthracnose
Stargazer	85	24-28	Allsweet rind, elongated; excellent quality; uniform; resistance to *Fusarium* and Anthracnose
Royal Sweet	85	20-24	Oblong; bright red flesh, small dark seeds; vigorous, resistant to *Fusarium*—shipper
SEEDLESS			
Melody	80	14-16	Allsweet rind, dark red flesh, intermediate resistance to Anthracnose 1 and *Fusarium* race 1
Fascination	83	16-20	Crimson Sweet rind; firm red flesh with good taste; good yield; resistance to *Fusarium*
Sweet Gem	79	13-16	Black rind; deep red firm flesh
Harvest Moon	90	8-13	Dark green rind with yellow spots. Seedless version of Moon and Stars. Excellent quality and because of the unique appearance it is well suited to farm markets and local production, AAS winner.
Captivation	89	14-17	Crimson Sweet rind with blocky shape. Deep red flesh color of good quality with high yields.
Unbridled	85	18-22	Allsweet rind pattern. Round fruit with crisp red flesh.
Troubadour	87	14-17	Allsweet rind; deep red flesh color of good quality; good yield
Treasure Chest	77	9-15	Jubilee rind; bright yellow flesh color; excellent quality
Revolution	82	16	Royal Sweet rind; elongated; bright red flesh; outstanding flavor; hollow heart tolerant
Ruby	85	14	Medium green dark double striped rind, oval; excellent dark red firm flesh; hollow heart tolerant
Crunchy Red	90	15	Crimson Sweet rind; dark pink flesh, blocky-round shape
Orange Crisp	92	14-18	Round oval shape, orange flesh, leave on vine longer to enhance flesh color.
MINI-SEEDLESS			
Ocelot	84	3-5	Dark tiger stripe rind, round, dark red flesh, excellent texture and taste.
Solitaire	85	6-9	Royal Sweet rind; round, attractive; very tough rind; very firm pink flesh

(continued on next page)

VARIETIES: Watermelon *(continued)*

Variety	DTM	Size (lb)	Comments[2]
POLLENIZER[3]			
Ace			Long vine, low growing, brittle fruit; susceptible to *Fusarium* and Anthracnose
Sidekick			Blooms very early; long vine; slightly more erect; small fruit
Accomplice			Bushy upright habit; consistent male flower production; hardy under early season cool conditions; moderate resistance to *Fusarium*

1 Days to maturity
2Watermelon varieties are often grouped by rind color or pattern; these groups or types are often named for a popular variety with similar characteristics:
All Sweet = medium green rind w/dark green, broad mottled stripes; Jubilee = light green rind with distinct narrow, dark green stripes; Black = solid dark green rind; Crimson Sweet = light green rind w/mottled dark green stripes; Royal Sweet = light green rind w/wide, mottled, dark green stripes.
3Pollenizers are used with seedless melons and planted in-row allowing for seedless melons to be grown in the entire field.

FERTILIZER: Vining Crops

Soil Test Results (lb/A)		Fertilizer Needed (lb/A)			
		Phosphate (P_2O_5)			
Phosphorus		**Cucumber**	**Melons**	**Squash/Pumpkin**	**Watermelon**
Low	<31	241-300	121-180	121-180	180
Medium	31-60	121-240	61-120	61-120	120
High	61-80	1-120	1-60	1-60	60
Very High	>80	0	0	0	0
		Potash (K_2O)			
Potassium		**Cucumber**	**Melons**	**Squash/Pumpkin**	**Watermelon**
Low	<201	201-300	101-150	201-300	150
Medium	201-300	101-200	51-100	101-200	100
High	301-450	51-100	1-50	51-100	50
Very High	>450	50	0	0-50	0

Nitrogen

Cucumbers: Apply 40 to 50 lb of nitrogen (N) per acre just before planting and disk into the soil. Sidedressing or topdressing an additional 30 to 50 lb of N per acre at first bloom is suggested. Rainfall, soil organic matter levels, and previous cropping history of land dictate nitrogen needs. Avoid applying N over tops of plants when foliage is wet. Applying granular fertilizer over the tops of plants when wet may burn the fruit as well as the foliage. A second sidedressing of 40 to 50 lb of N per acre may be necessary with some crops. See the "Fertigation" table (page 73) for slicing cucumbers grown on plastic mulch with drip irrigation.

Melons: Broadcast and disk into the soil 50 lb of N/A before planting. High rates of nitrogen early in the season increase vine growth, delay fruiting, and make pollination more difficult. As plants begin to vine, apply an additional 70 to 100 lb N/A in two sidedressings prior to fruit formation. See the "Fertigation" table (page 74) for fertigating nitrogen.

Squash and Pumpkins: Bare ground plantings: apply 75 to 80 lb N/A broadcast before planting. Apply 100 lb N/A if sod has been plowed under. Sidedress with an additional 50 lb N/A when vines begin to run. Reduce N application when manure is used; excess N may reduce fruit quality.

Summer squash on plastic with drip irrigation: apply 30 to 50 lb N/A preplant together with P and K recommendations. Fertigate an additional 50 to 75 lb N/A (see the "Fertigation" table, page 74).

Watermelon: Apply 50 to 70 lb N/A before planting. This should be broadcast and disked into the soil. As plants begin to vine, apply an additional 50 lb N/A as a sidedress (see the "Fertigation" table, page 74).

FERTIGATION: Vining Crops[1]

CUCUMBERS	
Actual N/week:	7 lb 12 oz/A
Calcium Nitrate	50 lb/A 2 lb 6 oz/1,000 plants

Total amount/season: 120 lb/A

Preplant amount: 50 lb/A

Fertigated amount: 70 lb/A

Growing season: 9 weeks

Fertigation should begin about 2 weeks after seedling emergence or two weeks after transplanting.

The doses for 1,000 plants are based on a plant population of 20,908 plants/A (i.e., beds on 5 foot centers with two rows per bed and single plants spaced 10 inches apart in the row; 12 to 18 inches between the double rows).

For seasons extending beyond 9 weeks, a maintenance dose of 1 to 1.5 lb N/acre/week is adequate.

(continued on next page)

FERTIGATION: Vining Crops[1] *(continued)*

MUSKMELONS, SPECIALTY MELONS	Total amount/season: 120 lb/A
Actual N/week: 8 lb 12 oz/A	Preplant amount: 50 lb/A
Calcium Nitrate: 56 lb 7 oz/A 15 lb 9 oz/1,000 plants	Fertigated amount: 70 lb/A
	Growing season: 8 weeks
	Fertigation begins about two weeks after transplanting or when vines begin to "run."
	The doses for 1,000 plants are based on a plant population of 3,630 plants/A (i.e., beds on 6 foot centers with single plants 2 feet apart in the rows).
	For seasons extending beyond 8 weeks from "running," a maintenance dose of 1 to 1.5 lb N/acre/week is adequate.
SQUASH	Total amount/season: 100 lb/A (moderate rate) 125 lb/A (high rate)
Moderate Rate	
Actual N/week: 5 lb/A	Preplant amount: 50 lb/A
Calcium Nitrate: 32 lb/A 7 lb/1,000 plants	Fertigated amount: 50 lb/A (moderate rate) 75 lb/A (high rate)
High Rate	
Actual N/week: 7 lb 8 oz/A	Growing season: 10 weeks
Calcium Nitrate: 48 lb/A 10 lb/1,000 plants	Fertigation can begin 14 days after transplanting.
	The doses for 1,000 plants are based on a plant population of 4,840 plants/A (i.e., rows on 6 foot centers and plants 18 inches apart in the rows).
	For seasons extending beyond 10 weeks a maintenance does of 1 to 1.5 lb N/acre/week is adequate.
WATERMELONS	Total amount/season: 120 lb/A
Actual N/week: 5 lb/A	Preplant amount: 60 lb/A
Calcium Nitrate: 32 lb 4 oz/A 17 lb 12 oz/1,000 plants	Fertigated amount: 60 lb/A
Icebox Types	Growing season: 12 weeks
Actual N/week: 5 lb/A	Fertigation begins about 2 weeks after transplanting or when vines begin to "run."
Calcium Nitrate: 32 lb 4 oz/A 8 lb 14 oz/1,000 plants	Standard melons: The doses for 1,000 plants are based on plant populations of 1,815 plants/A (i.e., beds on 8 foot centers with single plants 3 feet apart in the rows).
	Icebox melons: The doses for 1,000 plants are based on plant populations of 3,630 plants/A (beds on 6 foot centers and plants 2 feet apart in rows).
	For seasons extending beyond 12 weeks, a maintenance dose of 1 to 1.5 lb N/acre/week is adequate.

1 All recommendations assume starter fertilizer was used.

PESTICIDE SAFETY: Cucurbits

	Signal[1]	Re-entry (hrs)	Harvest (days)	NOT Approved for Use on: Cucumber	Melons	Squash/Pumpkin	Watermelon
INSECTICIDES							
Acramite 50 WS	C	12	3				
Actara 25 W	C	12	0				
Admire Pro	C	12	21				
Assail 30 SG	C	12	0				
Avaunt eVo 30 DG	C	12	3				
Belay 2.13 Sc	C	12	7/21[4]				
Beleaf 50 SG	C	12	0				
Coragen 1.67 SC	-	4	1				
Courier 40 SC	W	12	1				
Dimethoate 4 E	W	48	3	x		x	x
Entrust 2 SC	C	4	3				
Exirel 0.83 SE	C	12	1				
Fulfill 50 DF	C	12	0				
Harvanta 50 SL	C	4	1				
Intrepid 2 F	C	4	3				
Kanemite 15 SC	C	12	1			x	
Knack 0.86 EC	C	12	7				
Magister SC	W	12	3				
Malathion 8	C	24	1		x		x
Oberon 2 SC	C	12	7				
Platinum 2 SC	C	12	30				
Portal 0.4 EC	W	12	3			x	
PQZ 1.87 SC	C	12	1				
Radiant SC	C	4	1/3[4]				
Requiem 25 EC	C	4	0				

(continued)

PESTICIDE SAFETY: Cucurbits (continued)

	Signal[1]	Re-entry (hrs)	Harvest (days)	NOT Approved for Use on: Cucumber	Melons	Squash/Pumpkin	Watermelon
Rimon 0.83 EC	W	12	1				
Scorpion 35 SL	C	12	1/21[4]				
Sefina 0.42 SC	C	12	0				
Sevin XLR Plus	C	12	3				
Sivanto Prime 1.67 SL	C	12	1/21[4]				
Transform 50WG	D	24	1				
Torac 1.29 EC	W	12	1				
Trigard 75 WP	C	12	0				
Venom 70 SG	C	12	1/21[4]				
Verimark 1.67 SC	-	4	1				
Zeal 72 WP	C	12	7				
Restricted Use							
AgriMek 0.7 SC	W	12	7				
Asana XL	W	12	3				
Baythroid XL	W	12	0				
Brigade 2 EC	W	12	3				
Danitol 2.4 EC	W	24	7				
Diazinon AG500	C	24	3	x		x	
Diazinon 50 W	C	24	3	x		x	
Fastac 0.83 EC	D	12	1				
Lannate 90 SP	DP	48	1/3[4]				
Mustang Maxx	W	12	1				
Permethrin 3.2 EC	C	12	0				
Proclaim 5 SG	C	12	7				
Vydate 2 L	DP	48	1				
Warrior II	W	24	1				

PESTICIDE SAFETY: Vining Crops

	Signal[1]	Re-entry (hrs)	Harvest (days)	NOT Approved for Use on: Cucumber	Melons	Winter Squash/Pumpkins	Summer Squash	Watermelon
FUNGICIDES								
Actigard 50 WG	C	12	0					
Aprovia Top	D	12	0					
Ariston	C	12	3					
Azoxystrobin[2]	C	4	1					
Cabrio EG	C	12	0					
Cannonball WG	C	12	14	x		x	x	
Chlorothalonil[2]	D	12	0					
Fixed coppers[2]	D	24/48	0					
Curzate 60 DF	W	12	3					
Dexter Max	C	24	5					
Dexter XCEL	C	12	7					
Elumin	C	12	2					
Endura	W	12	0					
Flint	C	12	0					
Fluazinam[2]	W	12	7/30[3]					
Fluoxastrobin[2]	C	12	1		x			x
Fontelis	C	12	1					
Forum SC	C	12	0					
Gavel 75 DF	C	48	5					
Inspire Super	C	12	7					
Luna Experience	C	12	7					
Luna Sensation	C	12	0					
Mancozeb[2]	C	24	5					
Mandipropamid[2]	C	4	0					
ManKocide	D	24	5					
Merivon	W	12	0					
Metalaxyl[2]	W	48	0					
Miravis Prime	C	12	1					
Muscle	C	12	7					
Orondis Gold	C	4	0					
Orondis Opti	D	12	0					
Orondis Ultra	C	4	0					

(continued)

PESTICIDE SAFETY: Vining Crops *(continued)*

	Signal[1]	Re-entry (hrs)	Harvest (days)	NOT Approved for Use on: Cucumber	Melons	Winter Squash/Pumpkins	Summer Squash	Watermelon
Presidio	C	12	2					
Pristine	C	12	0					
Previcur Flex	C	12	2					
Procure 50 WS	C	12	0					
Proline 480 SC	C	12	7					
Quadris Opti	W	12	1					
Quadris Top	C	12	1					
Quintec	C	12	3	x			x	
Rally 40 WSP	W	24	0					
Ranman	C	12	0					
Reason 500 SC	C	12	14					
Rhyme	W	12	0					x
Ridomil Gold SL	C	48	0					
Ridomil Gold Bravo SC	W	48	0					
Ridomil Gold Copper	D	48	5					
Ridomil Gold MZ	C	48	5			x		
Sovran	C	12	0					
Sulfur[2]	C	24	0					
Switch 62.5 WG	C	12	1					
Tanos	C	12	3					
Tebuconazole[2]	C	12	7					
Thiophanate-methyl[2]	C	12	0					
Topguard	C	12	0		x			
Topguard EQ	C	12	1					
Torac	W	12	1					
Torino	C	4	0					
Uniform	C	0	AP					
Velum Prime	C	12	0					
Vivando	C	12	0					
Zampro	C	12	0					
Zing!	C	12	0					

1 W: Warning, C: Caution, D: Danger; P: Poison
2 Several formulations are marketed. See the general introduction for more details on fungicides.
3 Dependent on application or cucurbit type, see label.

INSECT CONTROL: Cucurbits[1,2]—Cucumber, Melon, Pumpkin, Squash, and Watermelon

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
PREPLANT INCORPORATED			
Wireworms, Cutworms: Wireworms are a potential problem for crops following grass or legume-grass sod.			
Diazinon 50 W	6 to 8 lb	8 lb	Incorporate immediately. For melons and watermelons only.
SOIL TREATMENTS			
Aphids, Cucumber Beetles, Whiteflies			
Admire Pro	7 to 10.5 fl oz	10.5 fl oz	See label for application methods.
Belay 2.13 SC	9 to 12 fl oz	12 fl oz	At planting only. See label for application methods. Also helps with squash bug.
Platinum 2 SC	5 to 11 fl oz	11 fl oz	See label for application methods.
Scorpion 35 SL	9 to 10.5 fl oz	21 fl oz	See label for application methods. Also helps with squash bug.
Sivanto Prime 1.67 SL	21 to 28 fl oz	28 fl oz	For aphids, leafhoppers and whiteflies.
Venom 70 SG	5 to 7.5 oz	12 oz	Allow 7 days between applications. Not for cucumber beetles or aphids.
Verimark 1.67 SC	6.75 to 13.5 fl oz	13.5 fl oz	At planting.
FOLIAR TREATMENTS			
Aphids			
Actara 25 WDG	1.5 to 3 oz	11 oz	Allow 5 days between applications.
Assail 30 SG	2.5 to 4 oz	26.5 oz	Limit 5 applications. Allow 5 days between applications.
Belay 2.13 SC	3 to 4 fl oz	12 fl oz	Allow 10 days between applications. Prior to 4th true leaf unfolding.
Beleaf 50 SG	2 to 2.8 oz	8.4 oz	Limit 3 applications at the 2.8 oz/A rate. Allow 7 days between applications.
Brigade 2 EC	2.6 to 6.4 fl oz	19.2 fl oz	Limit 2 applications after bloom. Allow 7 days between applications.
Exirel 0.83 SE	13.5 to 20.5 fl oz	61.5 fl oz	Allow 5 days between applications.
Fulfill 50 DF	2.75 oz	5.5 oz	Allow 7 days between applications.
Malathion 8	1 to 1.75 pt	2 applications	Allow 7 days between applications. For cucumbers, winter and summer squash only. Lower rate for winter squash.
PQZ 1.87 SC	2.4 to 3.2 fl oz	4.8 fl oz	Allow 7 days between applications. Limit 2 applications.
Scorpion 35 SL	2 to 7 fl oz	10.5 fl oz	Allow 7 days between applications. Do not combine with soil applications.
Sefina 0.42 SC	3 fl oz	28 fl oz	Allow 7 days between applications.
Sivanto Prime 1.67 SL	7 to 14 fl oz	28 fl oz	Allow 7 days between applications.
Transform WG	0.75 oz	8.5 oz	Allow 7 days between applications. Limit 4 applications.
Torac 1.29 EC	17 to 21 fl oz	42 fl oz	Allow 14 days between applications. Limit 2 applications.
Venom 70 SG	1 to 4 oz	6 oz	Allow 7 days between applications.
Cucumber Beetles: Key insect pest attacking cucumbers, vector of bacterial wilt. Must begin control when seedlings first emerge. Repeat applications as necessary to maintain control, particularly when plants are small. See Bacterial Wilt. Management can be relaxed when harvest begins.			
Asana XL	5.8 to 9.6 fl oz	48 fl oz	-
Assail 30 SG	2.5 to 5.3 oz	26.5 oz	Limit 5 applications. Allow 5 days between applications.
Belay 2.13 SC	3 to 4 fl oz	12 fl oz	Allow 10 days between applications. Prior to 4th true leaf unfolding
Brigade 2 EC	2.6 to 6.4 fl oz	19.2 fl oz	Limit 2 applications after bloom. Allow 7 days between applications.
Danitol 2.4 EC	10.67 to 16 fl oz	42.67 fl oz	Allow 7 days between applications.
Fastac 0.83 EC	3 to 3.8 fl oz	11.4 fl oz	Allow 7 days between applications.
Harvanta 50 SL	10.9 to 16.4 fl oz	49.2 fl oz	Allow 5 days between applications. Striped cucumber beetle only. Limit 3 applications.
Mustang Maxx	2.8 to 4 fl oz	24 fl oz	Allow 7 days between applications.
Permethrin 3.2 EC	4 to 8 fl oz	32 fl oz	Allow 7 days between applications.
Sevin XLR Plus	1 qt	6 qt	Allow 7 days between applications. Limit 6 applications.
Scorpion 35 SL	2 to 7 fl oz	10.5 fl oz	Allow 7 days between applications. Do not combine with soil applications.
Venom 70 SG	1 to 4 oz	6 oz	Allow 7 days between applications.
Warrior II	1.28 to 1.92 fl oz	11.5 fl oz	Allow 5 days between applications.

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INSECT CONTROL: Cucurbits[1,2] *(continued)*

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Cutworms: Eliminate weeds from field margins and plow fields at least 2 weeks before planting to destroy cutworm food sources and egg laying sites.			
Asana XL	5.8 to 9.6 fl oz	48 fl oz	-
Brigade 2 EC	2.6 to 6.4 fl oz	19.2 fl oz	Limit 2 applications after bloom. Allow 7 days between applications.
Fastac 0.83 EC	1.4 to 3.8 fl oz	11.4 fl oz	Allow 7 days between applications.
Permethrin 3.2 EC	4 to 8 fl oz	32 fl oz	Allow 7 days between applications.
Warrior II	1.28 to 1.92 fl oz	11.5 fl oz	Allow 5 days between applications.
Spider Mites: Regular weed control around the outside perimeter of the field is very important.			
Acramite 50 WS	0.75 to 1 lb	1 lb	Limit 1 application.
AgriMek 0.7 SC	1.75 to 3.5 fl oz	10.25 fl oz	Allow 7 days between applications. Must use non-ionic surfactant.
Brigade 2 EC	5.12 to 6.4 fl oz	19.2 fl oz	Limit 2 applications after bloom. Allow 7 days between applications. For end of season control.
Danitol 2.4 EC	10.67 to 16 fl oz	42.67 fl oz	Allow 7 days between applications. For end of season control.
Kanemite 15 SC	31 fl oz	62 fl oz	Limit 2 applications. Allow 21 days between applications.
Magister SC	24 to 36 fl oz	36 fl oz	Limit 1 application.
Miteus 0.42 EC	2 pt	4 pt	Limit 2 applications. Allow 14 days between applications.
Oberon 2 SC	7 to 8.5 fl oz	25.5 fl oz	Allow 7 days between sprays. Limit 3 applications.
Portal 0.4 EC	2 pt	4 pt	Limit 2 applications. Allow 14 days between applications.
Zeal 2.88 SC	4 to 6 oz	6 oz	Limit 1 application.
Squash Bug: Squash bug is a common pest of squash and pumpkins through feeding and transmission of the bacteria that causes Yellow Vine Decline. It also can transmit the disease to melons and watermelons. Destroy crop residues to reduce overwintering sites for squash bugs.			
Asana XL	5.8 to 9.6 fl oz	48 fl oz	-
Assail 30 SG	5.3 oz	26.5 oz	Limit 5 applications. Allow 5 days between applications.
Brigade 2 EC	2.6 to 6.4 fl oz	19.2 fl oz	Limit 2 applications after bloom. Allow 7 days between applications.
Fastac 0.83 EC	3 to 3.8 fl oz	11.4 fl oz	Allow 7 days between applications.
Mustang Maxx	2.8 to 4 fl oz	24 fl oz	Allow 7 days between applications.
Permethrin 3.2 EC	8 fl oz	32 fl oz	Allow 7 days between applications.
Rimon 0.83 EC	12 fl oz	36 fl oz	Allow 14 days between applications.
Scorpion 35 SL	2 to 7 fl oz	10.5 fl oz	Allow 7 days between applications. Do not combine with soil applications.
Sevin XLR Plus	1 qt	6 qt	Allow 7 days between applications. Limit 6 applications.
Sivanto Prime 1.67 SL	10.5 to 14 fl oz	28 fl oz	Allow 7 days between applications.
Venom 70 SG	1 to 4 oz	6 oz	Allow 7 days between applications.
Warrior II	1.28 to 1.92 fl oz	11.5 fl oz	Allow 5 days between applications.
Squash Vine Borer: Squash vine borer is primarily a pest of squashes and pumpkins. Treat for squash vine borer beginning 3rd week in June and repeat 3 to 5 times at weekly intervals.			
Asana XL	5.8 to 9.6 fl oz	48 fl oz	-
Assail 30 SG	5.3 oz	26.5 oz	Limit 5 applications. Allow 5 days between applications.
Brigade 2 EC	2.6 to 6.4 fl oz	19.2 fl oz	Limit 2 applications after bloom. Allow 7 days between applications.
Fastac 0.83 EC	3 to 3.8 fl oz	11.4 fl oz	Allow 7 days between applications.
Mustang Maxx	2.8 to 4 fl oz	24 fl oz	Allow 7 days between applications.
Permethrin 3.2 EC	4 to 8 fl oz	32 fl oz	Allow 7 days between applications.
Warrior II	1.28 to 1.92 fl oz	11.5 fl oz	Allow 5 days between applications.
Whiteflies			
Actara 25 W	3 to 5.5 oz	11 oz	Allow 5 days between applications.
Assail 30 SG	2.5 to 5.3 oz	26.5 oz	Limit 5 applications. Allow 5 days between applications.
Beleaf 50 SG	2 to 2.8 oz	8.4 oz	Limit 3 applications at the 2.8 oz/A rate. Allow 7 days between applications.
Closer 2 SC	4.25 to 4.5 fl oz	17 fl oz	Limit 4 applications. Allow 7 days between applications.
Courier 40 SC	9 to 13.6 fl oz	27.2 fl oz	Limit 4 applications. Allow 7 days between applications.
Exirel 0.83 SE	13.5 to 20.5 fl oz	61.5 fl oz	Allow 5 days between applications.
Knack 0.86 EC	8 to 10 fl oz	20 fl oz	Limit 2 applications. Allow 14 days between applications.
Magister SC	24 to 36 fl oz	36 fl oz	Limit 1 application.
Oberon 2 SC	7.0 to 8.5 fl oz	25.5 fl oz	Allow 7 days between sprays. Limit 3 applications.

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INSECT CONTROL: Cucurbits[1,2] *(continued)*

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Portal 0.4 EC	2 pt	4 pt	Limit 2 applications.
PQZ 1.87 Sc	2.4 to 3.2 fl oz	4.8 fl oz	Limit 2 applications. Allow 7 days between applications.
Requiem EC	2 to 3 qt	-	Note chlorothalonil incompatibility.
Rimon 0.83 EC	12 fl oz	36 fl oz	Allow 14 days between applications.
Scorpion 35 SL	2 to 7 fl oz	10.5 fl oz	Allow 7 days between applications. Do not combine with soil applications.
Sefina 0.42 SC	14 fl oz	28 fl oz	Allow 7 days between applications.
Sivanto 1.67 SL	10.5 to 14 fl oz	28 fl oz	Allow 7 days between applications.
Transform WG	2 to 2.25 oz	8.5 oz	Allow 7 days between applications. Limit 4 applications.
Venom 70 SG	1 to 4 oz	6 oz	Allow 7 days between applications.

1 See An IPM Scouting Guide for Common Problems of Cucurbit Crops in Kentucky (ID-91) for photos of pests.
2 Generic products available (Appendix G).

WEED CONTROL: Cucurbits - Cucumber, Melon, Pumpkin, Squash, and Watermelon

Product Amt/A	Lb A.I./A	Comments
The stale seedbed technique for direct seeded vine crops can be very effective in eliminating initial flushes of weeds occurring when soil is disturbed. This technique involves preparing the soil, allowing a flush of weeds to emerge, and then cultivating or applying paraquat before seeding or transplanting the crop. Paraquat will have no residual activity.		
0.5 to 1.6 fl oz Aim 1.9 EW	0.008 to 0.025 carfentrazone	For contact post-emergence control of annual broadleaf weeds and suppression of annual grasses. Do not confuse and use the non-labeled Aim EC formulation. Can be applied as a preplant, pre-transplant burndown, or before crop emerges to actively growing weeds up to 4 inches tall. Can also be applied post-emergence as a directed hooded application between crop rows. Use min. 10 gal water/A and crop oil 1% v/v. Max. rate 6.1 fl oz/A. PHI = 0 days.
0.4 to 1 pt Command 3ME	0.15 to 0.37 clomazone	Not labeled for gourd. For control of annual grasses and small-seeded broadleaves; poor control of pigweed. Apply immediately after seeding. Max. rate for muskmelon and watermelon is 0.67 pt/A. See label for additional instructions and restrictions. Label specifically states not to use on Jack-o-Lantern pumpkins due to unacceptable whitening. PHI = 45 days.
3 to 4.5 pt Curbit 3 E	1.13 to 1.5 ethalfluralin	Not labeled for gourd. For pre-emergence control of annual grasses and broadleaves. Do not use on wet or cloddy soils or before a heavy rain to avoid crop injury. Do not apply over or under hot caps, row covers, or plastic mulch. Do not apply broadcast to transplants. Do not incorporate. Clean cultivate and apply as a banded spray to soil between rows of plastic mulch.
6 to 14 lb Dacthal W-75	4.5 to 10.5 DCPA	Not labeled for pumpkin and some gourds. For pre-emergence control of annual grasses and small-seeded broadleaves. Apply only to crop with 4 to 5 true leaves that is well-established and when growing conditions are favorable. Do not incorporate. Not labeled for transplanted crop.
1.0 to 1.33 pt Dual Magnum	0.95 to 1.27 s-metolachlor	Pumpkin only. For pre-emergence control of select weed species. Leave at least 6 inches of untreated area on either side of hill or row and/or any pumpkin foliage. Direct contact with foliage will result in injury. PHI = 30 days.
2 to 4 pt Gramoxone Inteon	0.69 to 1.38 paraquat salt	For non-selective contact kill of annual grasses and broadleaf weeds and top-kill of perennial weeds. Apply preplant, pre-emergence, or before transplanting in min. 10 gal water/A. Apply banded or broadcast. Use higher rate for heavy weed infestations. Use non-ionic surfactant 0.25% v/v. **Paraquat product labels require applicators to take an EPA-approved training every 3 years to mix, load, and apply paraquat.**
0.5 to 1.5 pt Poast 1.5 E	0.09 to 0.27 sethoxydim	Not labeled for gourd. For control of actively growing grasses only. Use high rate on Johnson grass. PHI = 14 days. Max. rate of 1.5 pt/application and 4.5 pt/season.
5 to 6 qt Prefar 4 E	5 to 6 bensulide	For control of grasses and broadleaf weeds. Apply preplant and incorporate to 1 to 2 inch depth. Apply pre-emergence only if it can be watered in within 36 hours. Max. rate of 6 qt/season.
Reflex	fomesafen	Special Local Need 24(c) label for pumpkin, summer squash, winter squash, watermelon, and watermelon. GROWERS CAN ONLY OBTAIN THIS LABEL BY GOING TO THE SYNGENTA SPONSORED WEBSITE, https://www.syngenta-us.com/labels/indemnified-label-login AND REGISTERING AS A USER. ONCE AT THE WEBSITE, SELECT "PRODUCT", THEN "SPECIAL LABELS" THEN "INDEMNIFIED LABELS". YOU MUST REGISTER ONCE EVERY CALENDAR YEAR, BUT SUBSEQUENT ENTRIES INTO THE SITE DO NOT REQUIRE ADDITIONAL REGISTRATION.
16 to 22 fl oz Roundup WeatherMax 5.5L	0.69 to 0.94 glyphosate-salt	For non-selective post-emergence control of annual and perennial grasses and broadleaf weeds. Use only AMS 1 to 2% v/v. Adding a non-ionic surfactant can reduce weed control effectiveness. Min. 3 days between application and planting and min. 30 days before planting any non-labeled crop.

(continued on next page)

WEED CONTROL: Cucurbits - Cucumber, Melon, Pumpkin, Squash, and Watermelon *(continued)*

Product Amt/A	Lb A.I./A	Comments
0.5 to 1 oz Sandea 75 DF	0.023 to 0.047 halosulfuron	For control of broadleaf weeds and yellow nutsedge. Cucumber (30 days PHI), cantaloupe, and honeydew melon (57 days PHI): Can be applied preplant under plastic mulch. Apply after final bed preparation and before laying plastic and transplant 7 days after application. Can also be applied post-transplanting on bare ground. Check label for instructions for direct-seeded and row middle applications. Watermelon and muskmelon (57 days PHI): Apply only in row middles in direct-seeded and transplanted watermelon. If plastic mulch is used, do not spray Sandea on plastic. Check label for crop specific applications.
9 to 16 fl oz Select Max	0.07 to 0.12 clethodim	For selective post-emergence of actively growing annual grasses and suppression of perennial grasses. Add crop oil 1% v/v. Max. 16 fl oz/ application. Min. 14 days between applications. PHI = 14 days.
2 to 4 oz Sinbar 80 WP	0.1 to 0.2 terbacil	Watermelon only. For pre-emergence control of broadleaves and grasses. Apply after seeding but before watermelon emerges. For transplanted watermelons, apply pre-transplant. Sinbar may be used pre-emergence under plastic mulch or to row middles. Sinbar may also be applied broadcast over the plastic mulch prior to transplanting, or prior to punching holes in the plastic mulch for transplanting. Sinbar must be washed off the plastic mulch with a minimum of 0.5 inch rain prior to transplanting. PHI = 70 days.
3 to 6 pt Strategy 2.1E	0.6 to 1.18 ethalfluralin + 0.18 to 0.39 clomazone	Not labeled for gourd. For pre-emergence control of annual grasses and broadleaf weeds. Apply to seeded crop before its emergence or as a banded spray between rows after crop emergence or transplanting. Rainfall (0.5 inch) within 2 days is needed for activation. Do not incorporate. Crop injury may occur under cool temperatures that delay seedling emergence. PHI = 45 days for cucumber. Max. 1 application/year. Use lowest labeled rate for summer squash.
1.25 to 2 pt Treflan HFP 4 E	0.6 to 1 trifluralin	For control of annual grasses and broadleaf weeds. Apply after emergence to plants with 3 to 4 true leaves. Can be applied directed to soil between the rows to older plants but avoid foliage contact. PHI = 30 days for most cucurbits but 60 days for watermelon.

DISEASE CONTROL: Cucurbits—Cucumber, Melon, Squash and Pumpkin, Watermelon

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Angular Leaf Spot, Bacterial Leaf Spots [C/M/SP]					
Actigard	21	0	0.5 to 1 oz	16 oz	May cause phytotoxicity and yield reduction. Do not apply to stressed or injured plants.
Copper, fixed coppers	M	0			Tank-mix with mancozeb (EBDC fungicides) for maximum effectiveness. See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
ManKocide[3]	M	5	2 to 2.5 lb	see footnote	
Tanos	11/27	3	8 to 10 oz	4 apps	Suppression of bacterial fruit blotch. Tanos must be tank-mixed with copper for best results against bacterial disease.
Anthracnose and Alternaria Leaf Blight [C/M/SP/W], Cercospora Leaf Spot [C/M/W]					
Aftershock and fluoxastrobin[4] generics	11	3	3.0 to 5.7 fl oz	4 apps	
Aprovia Top	7/3	0	10.5 to 13.5 oz	53.6 oz	Spreading/penetrating-type adjuvant recommended.
Ariston	M/27	3	1.9 to 3 pt	17.5 pt	May sunburn mature watermelon.
Cabrio and pyraclostrobin[4] generics	11	0	12 to 16 oz[5]	4 apps	
Chlorothalonil[4]					Use higher rates for anthracnose and downy mildew. May cause sunburn on mature watermelon fruit. Do not tank mix or use surfactants for watermelon applications. There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Bravo Ultrex	M	0	1.4 to 2.7 lb	19 lb	
Bravo WeatherStik	M	0	1.5 to 3 pt	21 pt	
Dexter Max	M/11	5	2.1 to 3.2 lb	4 apps	See label for multiple tank mix limitations.
Copper, fixed coppers	M	0			See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Dexter XCEL	M/11/3	7	64 to 72 oz	4 apps	See label for multiple tank mix limitations.
Endura	7	0	6.5 oz[5]	4 apps	

(continued on next page)

DISEASE CONTROL: Cucurbits—Cucumber, Melon, Squash and Pumpkin, Watermelon *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Fontelis	7	1	12 to 16 fl oz	67 fl oz	Alternaria leaf blight.
Gavel 75 DF2	22/M	5	1.5 to 2 lb	8 apps	
Inspire Super	3/9	7	16 to 20 fl oz	80 fl oz	
Luna Experience	3/7	7	10 to 17 fl oz	34 fl oz	
Luna Sensation	7/11	0	4.0 to 7.6 fl oz	27.1 fl oz	
Mancozeb[3]					Some cantaloupe varieties are sensitive to Dithane F-45.
Dithane M45	M	5	2 to 3 lb	24 lb	There are multiple Dithane formulations and mancozeb generics on the market. See label for rates.
Dithane F-45	M	5	1.6 to 2.4 qt	8 apps	
ManKocide[3]	M	5	2 to 2.5 lb	see footnote	Use highest rates for Anthracnose.
Merivon	7/11	0	4 to 5.5 fl oz	3 apps	
Mettle	3	0	8.0 fl oz	5 apps	Apply prior to onset of disease; rotate to an alternate FRAC group between applications.
Miravis Prime	7/12	1	9.2 to 11.4 oz	22.8 oz	
Pristine	7/11	0	12.5 to 18.5 oz	4 apps	
Quadris and azoxystrobin[4] generics	11	1	11 to 15.5 fl oz	4 apps	
Quadris Opti	11/M	1	3.2 pt	4 apps	
Quadris Top	11/3	1	12 to 14 fl oz	56 fl oz	
Reason 500 SC	11	14	5.5 fl oz	4 apps	Alternaria leaf blight.
Ridomil Gold Bravo SC	4/M	0	2.5 to 3.25 pt	4 apps	
Switch 62.5 WG	9/12	1	11 to 14 oz	56 oz	Alternaria leaf blight.
Tanos	11/27	3	8 oz	4 apps	Tanos must be tank-mixed with a fungicide from FRAC Code M appropriate for the target disease.
Topsin M and thiophanate-methyl[4] generics	1	0	0.5 lb	5 apps	Anthracnose.
Topguard EQ	3/11	7	5 to 8 fl oz	4 apps	
Zing!	M/22	0	36 fl oz	8 apps	May cause sunburn on watermelon.
Bacterial Wilt [C/M/SP]: No bactericides available. Control of insect vectors is the only recommended practice—refer to the "Insect Control" table.					
Belly Rot, Fruit Rot (*Rhizoctonia*), Rhizoctonia root rot [C, M, S, P, W]					
Aftershock and fluoxastrobin[4] generics	11	1	3 to 5.7 fl oz	4 app	See label for application timing. For root rot, application method and rate may vary.
Quadris Opti	11/M	1	3.2 pt	4 apps	
Quadris Top	11/3	1	12 to 14 fl oz	56 fl oz	
Luna Experience	3/7	7	10 to 17 fl oz	34 fl oz	
Topsin M and thiophanate-methyl[4] generics	1	0	0.5 lb	5 apps	*Rhizoctonia* diseases; will not control *Pythium* or *Phytophthora*.
Topguard EQ	3/11	7	5.0 to 8.0 fl oz	4 apps	
Downy Mildew [C/M/SP/W]					
Actigard	21	0	0.5 to 1 oz	16 oz	May cause phytotoxicity and yield reduction. Do not apply to stressed or injured plants.
Aftershock and fluoxastrobin[4] generics	11	1	3 to 5.7 fl oz	4 app	
Ariston	M/27	3	1.9 to 3 pt	17.5 pt	May sunburn mature watermelon.
Cabrio and pyraclostrobin[4] generics	11	0	8 to 12 oz[5]	4 apps	

(continued on next page)

DISEASE CONTROL: Cucurbits—Cucumber, Melon, Squash and Pumpkin, Watermelon *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Chlorothalonil[4]					Use higher rates for downy mildew and anthracnose.
Bravo Ultrex	M	0	1.4 to 1.8 lb	19 lb	May cause sunburn on mature watermelon fruit. Do not tank mix or use surfactants for watermelon applications. There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Bravo Weather Stik	M	0	2 to 3 pt	21 pt	
Copper, fixed coppers	M	0			See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Curzate 60 DF	27	3	3.2 oz	9 apps	Must be tank-mixed with a fungicide from FRAC Code M.
Flint Extra	11	0	4 oz	4 apps	
Elumin	22	2	8 oz	2 apps	
Omega 500 and fluazinam[4] generics	29	30	12 to 24 fl oz		Soil drench or foliar application. See label for maximum number of applications. Note extended PHI.
Gavel 75 DF2	22/M	5	1.5 to 2	8 apps	
Mancozeb[4]	M	5			Some cantaloupe varieties are sensitive to Dithane F-45. There are multiple Dithane formulations and mancozeb generics on the market. See label for rates.
Dithane M45 and mancozeb[3] generics	M	5	2 to 3 lb	24 lb	
Dithane F-45	M	5	1.6 to 2.4 qt	8 apps	
ManKocide[3]	M	5	2 to 2.5		
Orondis Opti	49/M	0	1.75 to 2.5 pt	10 pt	Use only one Orondis product per year in the fungicide program. Avoid use on mature watermelons under challenging environmental conditions (see label).
Orondis Ultra	49/40	0	5.5 to 8 oz	32 oz	Use only one Orondis product per year in the fungicide program.
Presidio	43	2	3 to 4 fl oz	12 fl oz	Must be tank-mixed with a fungicide NOT in FRAC Group 43.
Previcur Flex	28	2	0.6 to 1.2 pt	6 pt	Use low rate when tank-mixing with other downy mildew fungicides.
Quadris and azoxystrobin[4] generics	11	1	11 to 15.5 fl oz	4 apps	See label for application timing. For root rot, application method and rate may vary.
Quadris Opti	11/M	1	3.2 pt	4 apps	
Ranman	21	0	2.1 to 2.75 fl oz	6 apps	Tank-mix with an organosilicone surfactant when disease pressure is severe; use an organosilicone or non-ionic surfactant when disease pressure is light-to-moderate.
Reason 500 SC	11	14	5.5 fl oz	22 fl oz	
Tanos	11/27	3	8 oz	4 apps	Tanos must be tank-mixed with a fungicide from FRAC Code M appropriate for the target disease.
Topguard EQ	3/11	7	5 to 8 fl oz	4 apps	
Viathon	3/33	7	4 pt	12 pt	Watermelon.
Zampro	40/45	0	14 fl oz	3 apps	
Zing!	M/22	0	36 fl oz	8 apps	May cause sunburn on watermelon.
Gummy Stem Blight (Black Rot) [C/M/S/P/W]					
Aftershock and fluoxastrobin[4] generics	11	1	3 to 5.7 fl oz	4 apps	
Ariston	M/27	3	3 pt	17.5 pt	May sunburn mature watermelon.
Chlorothalonil[4]					May cause sunburn on mature watermelon fruit. Do not tank mix or use surfactants for watermelon applications. There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Bravo Ultrex	M	0	1.4 to 2.7 lb	19 lb	
Bravo Weather Stik	M	0	1.5 to 3 pt	21 pt	
Copper, fixed coppers	M	0			See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Dexter Max	M/11	5	2.1 to 3.2 lb	4 apps	See label for multiple tank mix limitations.
Dexter XCEL	M/11/3	7	64 to 72 oz	4 apps	See label for multiple tank mix limitations.
Endura	7	0	6.5 oz	4 apps	

(continued on next page)

DISEASE CONTROL: Cucurbits—Cucumber, Melon, Squash and Pumpkin, Watermelon *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Fontelis	7	1	12 to 16 fl oz	67 fl oz	Alternaria leaf blight.
Inspire Super	3/9	7	16 to 20 fl oz	80 fl oz	
Luna Experience	3/7	7	10 to 17 fl oz	34 fl oz	
Luna Sensation	7/11	0	4 to 7.6 fl oz	27.1 fl oz	Suppressive only.
Mancozeb[4]					Some cantaloupe varieties are sensitive to Dithane F-45.
Dithane M45 and mancozeb[3] generics	M	5	2 to 3 lb	24 lb	There are multiple Dithane formulations and mancozeb generics on the market. See label for rates.
Dithane F-45	M	5	1.6 to 2.4 qt	8 apps	
ManKocide[3]	M	5	2 to 2.5 lb	see footnote	
Merivon	7/11	0	4 to 5.5 fl oz	3 apps	
Mettle	3	0	8.0 fl oz	5 apps	Suppression only.
Miravis Prime	7/12	1	9.2 to 11.4 oz	22.8 oz	
Muscle ADV	3/M	7	2.1 pt	6.4 pt	Test for phytotoxicity on watermelon.
Omega 500 and fluazinam[4] generics	29	30	12 to 24 fl oz		Soil drench or foliar application. See label for maximum number of applications. Note extended PHI.
Pristine	7/11	0	12.5 to 18.5 oz	4 apps	
Proline 480SC	3	7	5.7 fl oz	17.1 fl oz	
Quadris and azoxystrobin[4] generics	11	1	11 to 15.5 fl oz	4 apps	
Quadris Top	11/3	1	12 to 14 fl oz	56 fl oz	
Rhyme	3	0	5 to 7 fl oz	28 fl oz	Powdery mildew, gummy stem blight. Also may be drip administered for charcoal rot suppression.
Ridomil Gold Bravo	4/M	0	2 to 3 lb	4 apps	Avoid late-season applications.
Sovran	11	0	3.2 to 4.8 oz	4 apps	
Toledo and tebuconazole[4] generics	3	7	8 fl oz	24 fl oz	Also powdery mildew.
Topguard EQ	3/11	7	5 to 8 fl oz	4 apps	
Topsin M and thiophanate-methyl[4] generics	1	0	0.5 lb	5 apps	
Viathon	3/33	7	4 pt	12 pt	Watermelon.
Plectosporium (Microdochium; Plectosphaerella) Blight [CSP]					
Aftershock and fluoxastrobin[4] generics	11	1	3 to 5.7 fl oz	4 apps	
Cabrio and pyraclostrobin[4] generics	11	0	12 to 16 oz[5]	4 apps	
Dexter Max	M/11	5	2.1 to 3.2 lb	4 apps	See label for multiple tank mix limitations.
Dexter XCEL	M/11/3	7	64 to 72 oz	4 apps	See label for multiple tank mix limitations.
Flint Extra	11	0	1.5 to 2.0 oz	16 oz	
Inspire Super	3/9	7	16 to 20 fl oz	80 fl oz	
Mancozeb[4]					Some cantaloupe varieties are sensitive to Dithane F-45.
Dithane M45 and mancozeb[3] generics	M	5	2 to 3 lb	24 lb	There are multiple Dithane formulations and mancozeb generics on the market. See label for rates.
Dithane F-45	M	5	1.6 to 2.4 qt	8 apps	
Merivon	7/11	0	4 to 5.5 fl oz	3 apps	
Quadris and azoxystrobin[4] generics	11	1	11 to 15.5 fl oz	4 apps	

(continued on next page)

DISEASE CONTROL: Cucurbits—Cucumber, Melon, Squash and Pumpkin, Watermelon *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Quadris Top	11/3	1	12 to 14 fl oz	56 fl oz	
Topguard EQ	3/11	7	5 to 8 fl oz	4 apps	
Phytophthora Blight [C/M/SP/W]					
Elumin	22	2	8 oz	2 apps	Can be applied via drip irrigation or as a soil-directed spray.
Forum SC	40	0	6 fl oz	5 apps	Must be tank-mixed with a protectant fungicide.
Omega 500 and fluazinam[4] generics	29	30	12 to 24 fl oz		Soil drench or foliar application. See label for maximum number of applications. Note extended PHI.
Orondis Gold	49	0	4.8 to 9.6 fl oz	19.2 fl oz	Use only one Orondis product per year in the fungicide program.
Orondis Ultra	49/40	0	5.5 to 8 oz	32 oz	Use only one Orondis product per year in the fungicide program.
Presidio	43	2	3 to 4 fl oz	12 fl oz	Must be tank-mixed with a fungicide NOT in FRAC Group 43.
Ranman	21	0	2.75 fl oz	6 apps	Tank-mix with an organosilicone surfactant when disease pressure is severe; use an organosilicone or non-ionic surfactant when disease pressure is light-to-moderate.
Revus	40	0	8 fl oz	32 fl oz	Use a spreader/penetrant surfactant. Must be tank-mixed with a fungicide NOT in FRAC Group 40.
Tanos	11/27	3	8 to 10 oz	4 apps	Tanos must be tank-mixed with a fixed copper plus mancozeb fungicide.
Zampro	40/45	0	14 fl oz	3 apps	
Powdery Mildew [C/M/SP/W]					
Actigard	21	0	0.5 to 1 oz	16 oz	May cause phytotoxicity and yield reduction. Do not apply to stressed or injured plants.
Aftershock and fluoxastrobin[4] generics	11	1	3 to 5.7 fl oz	4 apps	
Ariston	M/27	3	3 pt	17.5 pt	May sunburn mature watermelon.
Chlorothalonil[4]					May cause sunburn on mature watermelon fruit. Do not tank mix or use surfactants for watermelon applications. There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Bravo Ultrex	M	0	1.4 to 2.7 lb	19 lb	
Bravo Weather Stik	M	0	1.5 to 3 pt	21 pt	
Copper, fixed coppers[4]	M	0			See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Dexter Max	M/11	5	2.1 to 3.2 lb	4 apps	See label for multiple tank mix limitations.
Dexter XCEL	11	3	3 to 5.7 fl oz	4 apps	
Flint Extra	11	0	1.5 to 2 oz	16 oz	
Fontelis	7	1	12 to 16 fl oz	67 fl oz	
Luna Experience	7/3	7	6 to 17 fl oz	34 fl oz	
Luna Sensation	7/11	0	4 to 7.6 fl oz	27.1 fl oz	
Merivon	7/11	0	4 to 5.5 fl oz	3 apps	
Mettle	3	0	8 fl oz	5 apps	
Miravis Prime	7/12	1	9.2 to 11.4 oz	22.8 oz	
Muscle ADV	3/M	7	1.1 to 1.6 pt	6.4 pt	Test for phytotoxicity on watermelon.
Pristine	7/11	0	12.5 to 18.5 oz[5]	4 apps	
Procure 50 WS	3	0	4 to 8 oz	40 oz	
Proline 480SC	3	7	5.7 fl oz	17.1 fl oz	
Quadris Opti	11/M	1	3.2 pt	4 apps	
Quadris Top	11/3	1	12 to 14 fl oz	56 fl oz	
Quintec	13	3	4 to 6 fl oz		Muskmelon, gourd, pumpkin, watermelon, and winter squash only.
Rally 40 WSP	3	0	2.5 to 5 oz	1.5 lb	

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DISEASE CONTROL: Cucurbits—Cucumber, Melon, Squash and Pumpkin, Watermelon *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Rhyme	3	0	5 to 7 fl oz	28 fl oz	Powdery mildew, gummy stem blight. Also may be drip administered for charcoal rot suppression.
Sovran	11	0	3.2 to 4.8 oz	4 apps	
Sulfur[4]	M				Phytotoxicity may occur when sulfur is applied when temperatures exceed 90ºF.
Toledo and tebuconazole[4] generics	3	7	4 to 6 fl oz	24 fl oz	Use lowest listed rate of surfactant to improve coverage.
Topguard	3	0	10 to 14 fl oz	56 fl oz	Powdery mildew, gummy stem blight.
Topguard EQ	3/11	7	5 to 8 fl oz	4 apps	
Topsin M and thiophanate-methyl[4] generics	1	0	0.5 lb	5 apps	
Torac	39	1	21 oz	2 apps	Also an insecticide.
Torino	U6	0	3.4 fl oz	2 apps	
Trionic	3	1	4 to 8 fl oz	4 apps or 24 fl oz	Powdery mildew.
Velum Prime	7	0	6.5 to 6.84 oz	2 apps	Also suppresses nematodes. Drip-administered applications are effective against powdery mildew.
Viathon	3/33	7	2 to 3 pt	12 pt	Watermelon only.
Vivando	U8	0	15.4 fl oz	3 apps	Do not mix with horticultural oils and alternate with a different FRAC code.
Pythium Damping-off and Cottony Leak [C/M/SP/W]					
MetaStar and metalaxyl[4] generics	4	0	4 to 8 pts	1 app	Preplant or at planting. May be applied through drip irrigation.
Previcur Flex	28	2	1.2 pt	6 pt	Pythium root rot, seedling diseases only. Field and greenhouse use; may be applied through drench or drip irrigation.
Ridomil Gold SL	4	0	1 to 2 pt	1 app	Preplant or at planting. May be applied through drip irrigation.
Scab [C/M/SP/W]					
Actigard	21	0	0.5 to 1 oz	16 oz	May cause phytotoxicity and yield reduction. Do not apply to stressed or injured plants.
Chlorothalonil[4]					May cause sunburn on mature watermelon fruit. Do not tank mix or use surfactants for watermelon applications.
Bravo Ultrex	M	0	1.8 to 2.7 lb	19 lb	
Bravo Weather Stik	M	0	1.5 to 3 pt	21 pt	There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Copper, fixed coppers[4]	M	0			See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Mancozeb[4]					Some cantaloupe varieties are sensitive to Dithane F-45.
Dithane M45 and mancozeb[3] generics	M	5	2 to 3 lb	24 lb	There are multiple Dithane formulations and mancozeb generics on the market. See label for rates.
Dithane F-45	M	5	1.6 to 2.4 qt	8 apps	
Miravis Prime	7/12	1	9.2 to 11.4 oz	22.8 oz	
Ridomil Gold Bravo SC	4/M	0	2.5 to 3.25 pt	4 apps	Avoid late-season applications.

1 Products with numerical FRAC codes must be alternated or tank-mixed with products that have a different FRAC code to discourage resistance development. See product label for maximum number of consecutive applications allowed. Refer to the table on pages 22-24 for more information on FRAC codes.
2 Pre-harvest interval.
3 Observe seasonal limits for mancozeb.
4 Generic products available (Appendix F). Amounts and seasonal limits per acre are product dependent.
5 Use higher rate when pressure is severe.

Eggplant

Nightshade family (Solanaceae): *Solanum melongena*

For information on eggplant see "Fruiting Vegetables" section on page 86

Fruiting Vegetables (Tomato, Pepper, & Eggplant)

Nightshade family (Solanaceae): *Solanum melongena, Capsicum annuum, Solanum lycopersicum*

Planting and Culture

Eggplant

Eggplants need warm soil and warm air temperatures to yield well. Sample soil and consult soil test results and apply preplant fertilizer based on soil test recommendations. After the danger of frost has passed (see Appendix K), transplant into rows 36 to 42 inches apart with plants 18 to 24 inches apart in the rows. Plant on a well-drained loam soil for best results. Prepare the starter fertilizer by mixing 3 pounds of 10-52-17 or similar analysis water-soluble fertilizer in 50 gallons of water. Immediately following transplanting, flea beetles must be carefully monitored and treated if necessary. Yields of large-fruited varieties are in the range of 12 to 15 tons per acre of marketable fruit. Eggplant benefits from irrigation at flowering and fruit set if soil moisture is low.

Eggplants are most productive on black plastic with trickle irrigation. Mulched beds are usually spaced 5 to 6 feet apart with individual plants spaced 18 to 24 inches apart within the row. The recommendations in the "Fertigation" table are based on a plant population of 4,356 plants per acre (beds on 5-foot centers and 24 inches between plants within rows). Fertigation should begin about two weeks after transplanting and continue throughout the season. Growers may need to modify these guidelines depending on soil type, previous crop, etc. Eggplants may benefit from staking or trellising similar to that used in tomatoes. Staking helps prevent late-forming fruit from pulling the branches over to the ground.

Pepper

Peppers are grown primarily for the fresh market in Kentucky. To be successful it is important to begin by selecting a good field location. Low-lying fields next to creeks and rivers are subject to high humidity and moisture conditions that result in serious disease risks; these areas are especially prone to bacterial leaf-spot epidemics. Avoid poorly drained fields or fields where imazaquin or atrazine herbicides may have been used the previous season. Herbicide carryover (especially from corn and soybean herbicides) can cause serious injury to peppers (see "Weed Management" on page 14).

Growers also should locate pepper plantings as far away from tobacco plantings as possible because of the danger of aphid movement and virus disease spread from tobacco to peppers. Although tobacco ground may represent some of the best land on a farm, it is also not advisable to grow peppers after tobacco, tomatoes, eggplants, potatoes, or vining crops for a period of three years, because these crops are susceptible to many of the same diseases.

Soils known to be high in residual nitrogen should also be avoided to prevent peppers from producing excessive foliage at the expense of fruit. Consider the previous crop when deciding how much nitrogen to apply; there will probably be some residual nitrogen following a crop that received heavy doses of nitrogen fertilizer during the previous season.

Potassium and especially phosphorus are likely to accumulate in most Kentucky soils following several years of heavy applications for vegetable crops. Make sure to get your soil tested in the fall or early winter so that you will know exactly what nutrients are required.

Plow soil 8 to 10 inches deep several weeks in advance of the transplanting date. Peppers do extremely well following fescue sod. Prepare a fine seedbed by disking or rototilling.

Fresh Market Bell Peppers-- Production with Plasticulture

Planting hybrid bell peppers on 6- to 8-inch-high raised beds covered with black plastic mulch and using drip irrigation has resulted in high yields of excellent quality peppers for fresh market sales. A bed shaper/ plastic mulch layer and a setter that will transplant through plastic are essential for this production system. Two rows of peppers spaced 15 inches apart are planted on each bed; plants are spaced 12 to 15 inches apart within each row. The beds are usually 5 to 6 feet from center to center (approximately 14,500 plants per acre).

Since a portion of the fertilizer will be applied though the drip irrigation system (fertigation), uniform watering will ensure that plants receive adequate nutrients. Don't assume that because it has rained there will be water in the root zone under plastic. Also, while the consequences of under-watering (and therefore under-fertilizing) are obvious, many growers overlook the fact that over-watering will leach nutrients out of the root zone. Growers using trickle irrigation and plastic mulch should carefully monitor soil moisture using tensiometers. Check these instruments daily. For more details on how to set up a trickle irrigation system with fertilizer injection,

contact your county Extension agent or irrigation supply representative.

In Kentucky, pepper plants should be transplanted to the field after danger of frost, usually around the second week of May (see Appendix K). A 7- to 8-week-old transplant is best.

Greenhouse container-grown plants are recommended for planting with mulch and trickle irrigation. Trays with 72-128 cells are considered economical but large enough to produce large and vigorous transplants. Using a larger transplant container (larger cell size) will usually result in better transplant survival and earlier yields.

Seed should be treated by the seed company or treated with chlorine bleach by the grower to help reduce seed transmission of bacterial leaf spot (see Appendix I). Bacterial spot remains a serious risk to pepper plantings in many parts of the state, and most growers should use resistant varieties as well as early-season sprays containing fixed copper plus manzate to reduce ephypitic populations of leaf spot bacteria. Bare root transplants are not recommended for fresh market pepper production.

When transplanting, use 4 to 8 ounces of a starter solution around the roots of each plant. Use 3 pounds of a 10-52-17 or similar analysis fertilizer in 50 gallons of water for the starter mix.

Poor fruit set and deformed fruit may result when nighttime temperatures drop below 60°F or when daytime temperatures exceed 90°F. Varieties differ considerably in their response to temperature extremes.

Most types of hot and specialty peppers can be grown using the same techniques and spacings as for bell peppers; however, some types require staking and tying**.** Serrano peppers, anaheims, poblanos, and some cubanelle varieties should be staked and tied when using plasticulture and high plant populations. Tomato stakes are placed every 6 to 10 feet on each side of the double-row beds. Tomato twine is looped and tightened around each stake at 7 to 9 inches above the soil to "fence-in" the plants. Second and third stringings can be used higher on the stakes as needed during the season. To reduce sunburn to fruit, shorter (2½ to 3 feet) stakes are sometimes also used for very tall bell pepper varieties or where bell pepper plantings are exposed to high winds.

Peppers for Processing

There are few processing peppers being produced in Kentucky. Peppers grown for processing are usually transplanted 16 inches apart in single rows 36 to 42 inches apart, which will require about 10,000 plants per acre. If pimento peppers are grown, space plants 18 to 22 inches apart in rows 40 to 42 inches apart (7,500 plants per acre). Although processing peppers have traditionally been grown on bare ground in Kentucky, several growers in recent years have doubled their profits by using higher plant populations, hybrid varieties, and black plastic mulch with drip irrigation.

Given the higher cost of the raised bed/plasticulture production system, most processors do not object to growers selling a portion of the crop as fresh greens. In fact, it has become very common for growers to sell the first harvests as green peppers for the fresh market and sell later-maturing fruits as red peppers for processors. Yields can be dramatically increased with plastic and drip irrigation, especially in a dry season.

Techniques (including double-row spacings) for using this system with processing peppers are the same as those described for fresh market peppers (see page 86).

Growers contracting with a processor, however, are advised to check with the processing company regarding varieties. Due to the devastating nature of bacterial leaf spot on peppers in Kentucky it is advised that growers use a hybrid variety with leaf spot resistance. Some processors may supply open-pollinated, non-resistant varieties. The risks of using a non-resistant variety are too great for large wholesale growers in Kentucky and should be avoided.

Tomato

Staked tomatoes for fresh market sales have been most profitable when planted and given protection for the very early market or when planted for a late fall crop and harvested just before frost. Tomatoes are usually transplanted during the latter part of April or early May for the spring crop and in mid-July for the fall crop (see Appendix K). A well-drained soil that warms up quickly in the spring is most desirable. Be careful following corn or soybeans because common herbicides used in these crops can be very damaging to tomatoes (see the "Herbicide Label Restrictions" table on page 16). Also be wary of plantings close to your neighbor's corn, soybeans, or small grains, because tomatoes are very sensitive to herbicide drift from these crops. If possible, avoid low-lying fields subject to late frosts and high humidity.

Think twice about locating your tomato planting on land used for tobacco. Although tobacco ground may represent some of the best land on a farm, it is not advisable to grow tomatoes (or peppers or potatoes) after tobacco for a period of at least three years because these crops are susceptible to many of the same diseases. Tomatoes should also not follow tomatoes on the same land for a period of at least three years. Tomatoes should not be grown in short rotation with crops in the same family (tobacco, peppers, potatoes, eggplant, etc.) nor with any of the vine crops (cucumbers, squash, pumpkins, melons, etc.) as all of these are susceptible to Phytophthora blight. Tomatoes do well when transplanted to fields where fescue sod was plowed under the previous fall. Soil should be plowed 8 to 10 inches deep and disked well in the spring to produce a firm plant bed.

Stocky, container-grown plants are most desirable for transplanting. Although it is possible to use bare root plants on bare ground plantings,

higher early yields will be obtained from container-grown plants. Larger cell trays or containers (up to 3 inches) produce higher early yields than small containers or bare root plants. Early tomatoes generally command higher prices, which usually more than offset the higher cost of good quality, container-grown plants. During transplant production, the greenhouse temperature should not be allowed to drop below 60°F, or the fruit in the first few clusters may become cat-faced.

Most growers use approximately 4,200 to 5,000 plants per acre. Plants are usually grown in rows 6 feet apart with plants 18 to 22 inches apart in the row. Most varieties should be pruned, staked, and trellised to obtain higher and earlier yields. A satisfactory trellis (Figures 1a and 1b) may be constructed using 1-inch-square, 5-foot-long stakes driven 10 to 12 inches into the soil between every other plant (approximately 2,100 to 2,500 stakes per acre). A simple, hand-operated stake-driving tool can be made from a 36-inch length of 2½-inch galvanized pipe with a cap screwed or welded on one end. Slide the pipe down over the stake, striking down repeatedly with force to drive stakes.

The first stringing should be about 10 inches above the soil and should be done when the plants are 12 to 15 inches high. A simple stringing tool can be made by drilling holes in each end of a short length of broomstick. Tomato twine is passed though the holes in the tool, which is used to pass the string along one side of the row, looping the string around each stake. It is important to keep the twine pulled tight. Proceed to the end of the row and return on the opposite side passing the string along the other side of the plants, again looping each stake. It is helpful at the first stringing to cross the string between plants (Figure 1a). To maintain a well-trained system, subsequent strings should be put up as the plants grow. Three to four stringings are desirable, each about 6 to 10 inches higher than the preceding one. "Crossing over" or weaving with twine between plants, is not necessary after the first stringing (Figure 1b).

Pruning will help maintain the desired balance between vegetative growth and fruit production. Little or no pruning results in more vine growth with a heavier load of smaller fruit. Moderate pruning results in a smaller vine and larger fruit that mature earlier. Except for small-vined, very early-maturing tomato varieties such as 'Sunshine' (which should not be pruned at all), remove all suckers up to the one immediately below the first flower cluster (Figure 2). Leave this lateral shoot to form a fork just below the first fruit cluster. A single pruning when basal suckers are no longer than 3 or 4 inches will usually be adequate (especially on large fruited cultivars).

At transplanting, a starter fertilizer mix can be applied to each plant. Prepare the starter fertilizer by mixing 3 pounds of a 10-52-17 or similar analysis fertilizer in 50 gallons of water and applied in the transplant holes.

Higher yields and profits will be obtained using a system of producing tomatoes on 6- to 8-inch raised beds covered with black plastic mulch with drip irrigation and fertigation. Most growers prefer embossed plastic mulch, which seems to be more durable and tear-resistant than smooth plastic. When using the plasticulture system, it is extremely important to monitor moisture levels under the plastic. Many Kentucky growers have substantially reduced their yields and fruit size by incorrectly assuming that if the field is muddy between the rows, there is sufficient moisture beneath the plastic. Use tensiometers to monitor soil moisture levels and check them daily to determine

Figure 1a.

Cross over between plants when weaving the first row.

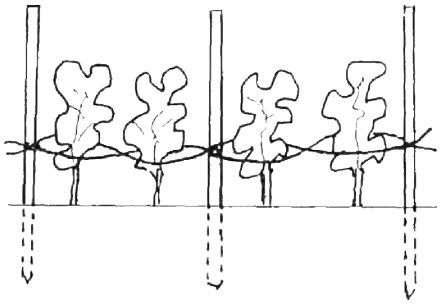


Figure 1b.

Second, third, and fourth rows of twine are pulled along sides of plants without crossing over.

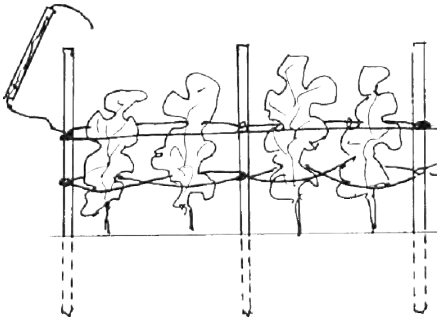
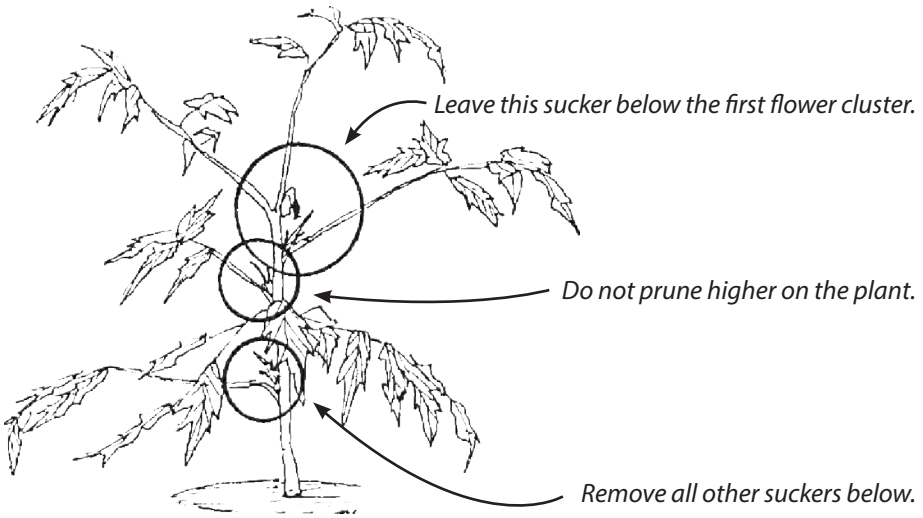


Figure 2.



irrigation intervals. Two tensiometers are recommended, one at a 6-inch depth and one at 12 inches. Contact your county Extension agent or irrigation supply sales representative for more information on setting up a drip irrigation/fertigation system.

Fertilizing

Eggplant

Lime the soil if needed to obtain a soil pH of 6.0 to 6.8. Too much early nitrogen results in large plants, delayed maturity, and stem breakage. For eggplants grown using plastic mulch and drip irrigation, apply all phosphorus and potassium and a portion of the total nitrogen requirement prior to laying plastic. The remaining N requirement can be fertigated in weekly doses (see "Fertigation" table).

Pepper

For fresh-market bell pepper production on most medium-textured soils where plastic mulch and drip irrigation are being used, we recommend that all of the phosphorus, all the potassium, and 50 percent of the nitrogen requirement be applied prior to bedding and laying plastic.

Consider the previous crop when deciding how much nitrogen to apply; there will probably be some residual nitrogen following a crop that received heavy doses of nitrogen fertilizer during the previous season. The fertigated portion of the total nitrogen requirement can be divided into equal amounts (remaining nitrogen requirement divided by the number of weeks until final harvest) and injected weekly as in the "Fertigation" table (based on 14,500 plants per acre). Growers with very sandy soils should also consider applying 50 to 60 percent of their potassium requirement in weekly increments through the drip system in addition to nitrogen.

Growers should always have annual soil test results on which to base phosphorus and potassium applications. Potassium and especially phosphorus are likely to accumulate in most Kentucky soils following several years of heavy applications for vegetable crops or tobacco. A pH range of 6.5 to 7.0 is best for peppers, and liming may be required if soil pH falls below 6.0. For bare ground plantings apply 50 pounds of nitrogen per acre preplant. Apply one-half at plowing and one-half just prior to transplanting, and disk into the soil.

For processing bell pepper production where plastic mulch is not used, sidedressing or banding additional nitrogen to either side of the plant when the first fruit begin setting is essential for good yields. Apply 30 pounds of nitrogen per acre at the first sidedressing. A second sidedressing of 30 pounds of nitrogen two weeks later should also be applied.

Tomato

Growing a high-investment, high-dollar crop such as staked tomatoes requires that the best information available be used whenever possible. Soil testing is an important tool that should always be used to determine fertilizer needs. Apply lime if needed to raise the pH to 6.5 to 6.8. Apply phosphate, potash, magnesium, and calcium as required based on soil test results. Soil test magnesium levels should be 200 pounds per acre (see Appendix B). Potassium and especially phosphorus are likely to accumulate in most Kentucky soils following several years of heavy applications for vegetable crops or tobacco.

Consider the previous crop when deciding how much N to apply; there will probably be some residual N following a crop that received heavy doses of N fertilizer during the previous season. Apply 50 pounds of N per acre preplant regardless of the type of irrigation system used. Simple, handheld electronic meters are available that growers can use to quickly determine the nitrogen status of soils and plants. These Cardy meters can be used to determine residual nitrate levels in soils prior to planting as well as measure N levels in plant sap in order to assess the efficiency of fertigation.

The fertigation recommendations have worked well for growers in Kentucky when tomatoes are grown on black plastic mulch with drip irrigation. This schedule is based on a standard plant population of 4,200 plants per acre (five-row blocks, beds on 6-foot centers and 18 inches between plants within rows) using the 'Mountain Spring' variety. Fertigation should begin about 10 days after transplanting and continue throughout the season. A grower may need to modify the recommendations slightly depending on length of harvest period, soil type, previous crop, weather conditions, etc.

Calcium nitrate and potassium nitrate are commonly used water-soluble sources of nitrogen. The simplest system that has worked well on medium-textured soils in Kentucky uses calcium nitrate or potassium nitrate injected into the drip irrigation water.

Soil tests and ripening disorders.

A soil test should always be done prior to planting for every site used for fresh market tomatoes. Ideally, a soil test would be conducted the fall before a spring planting in order to allow time for lime or sulfur applications which can take several months to take effect in the soil. The University of Kentucky soil test reports for tomatoes now also include a Hartz ratio calculation. Based on the nutrient balance in your soil, the Hartz ratio indicates if your site may be at risk for certain types of fruit-ripening disorders such as blotchy ripening, yellow shoulder, and internal white tissue. This information helps determine the type of fertilization program that should be followed to help reduce your risk of having these disorders.

More often than not, ripening problems are associated with low levels of soil potassium and occur most often on soils with low cation exchange capacities (CECs). If the Hartz ratio indicates that your soil is at risk, we recommend applying potassium prior to planting (according to the soil test report recommendations) and following with fertigation during the season

with a potassium source such as water-soluble muriate of potash (0-0-60) or potassium nitrate (14-0-45). See the "Fertigation" table for recommended rates. This is in addition to any preplant potassium.

Ripening disorders have also been associated with excess nitrogen and any conditions that restrict the tomato plant's root system (soil compaction, waterlogging, drought, etc.). During hot, dry years every other fertigation should contain potassium nitrate. More blotchy ripening occurs after extended periods of cloudy weather. Some tomato varieties are much more susceptible to blotchy ripening than others. Typically, varieties recommended in this publication, while not immune to blotchy ripening, are less susceptible.

Magnesium deficiencies.

Mild magnesium deficiencies sometimes appear at midseason on plants with very heavy fruit loads. A typical symptom is yellowing between the veins (veins remain green) on the lower leaves of the plant. Magnesium deficiency problems are more likely to occur on sandstone-derived soils and in very dry years.

Frequent fertigations with potassium or calcium nitrate could make the problem worse by competing with and displacing magnesium in soils. Mild symptoms are not generally a problem, and corrective measures are not necessary; however, symptoms may become severe and appear on the entire lower portion of the plant. In such cases, and especially on low CEC soils, preventive and/or corrective measures are required.

In general, it is recommended to have 200 pounds per acre of magnesium on soil tests for staked tomatoes prior to planting. Magnesium sources include dolomitic lime (11 to 12% Mg), epsom salts (= magnesium sulfate, 10 to 16% Mg), magnesium nitrate (6.3% Mg), and magnesium oxide (45 to 55% Mg). Epsom salts and magnesium oxide can be fertigated through the drip system: make weekly applications of 1 to 2 pounds actual magnesium per acre (10 to 20 pounds per acre epsom salts or 2 to 4 pounds per acre magnesium oxide). Application rates may vary with solubility of the materials (check with the manufacturer). A better long-term solution is to raise soil test magnesium levels with dolomitic lime prior to planting. Be careful to not over-apply magnesium as it can compete with potassium for uptake by the plant which can contribute to ripening disorders, specifically yellow shoulder.

Harvesting, Grading, and Marketing

Eggplant

The time required from flowering to marketable fruit size is about three weeks. Large fruit should weigh in the range of three quarters to 1 pound. Oriental type fruit should weigh one third to of half of a pound. The principal market container is a 1⅑ bushel fiberboard carton, 18 to 21 fruit per box.

Harvest fruit when they reach a dark, glossy, uniform, purple-black color. They should be firm (non-wrinkled). Wipe fruit clean or wash. Frequent pickings will result in higher yields.

Cut the stem from the plant. The calyx and stem should be fresh green in color. For transit and storage, hold eggplants at a temperature of 45° to 50°F and 90 to 95 percent relative humidity. Handle fruit carefully, as they bruise easily.

Pepper

Mature green peppers ready for harvest will be firm and will have attained their maximum size. Fresh market green peppers are normally harvested when firm and before they lose their dark green color. Harvest peppers for processing when red ripe.

Peppers should be handled carefully when picking and dumping to avoid bruising and punctures. Hard and rough picking containers may cause skin breakage or punctures and should be avoided. Do not use plastic bags, because peppers will heat up and quickly decay.

Pack only clean, undamaged, insect- and disease-free peppers. Peppers are graded into "U.S. Fancy" (not less than 3 inches in diameter and not less than 3½ inches long) and U.S. No. 1 (not less than 2½ inches in diameter or length).

All grades must have similar varietal characteristics, be firm, fairly well shaped, and free from damage caused by freezing injury, hail, scars, sunburn, disease, insects, or mechanical or other means. Free copies of USDA standards for grades of peppers and other fruit and vegetables are available on the Web at ams.usda.gov/AMSv1.0/freshmarketvegetablestandards.

Cool peppers to 45° to 50°F by putting them in the cooler as soon as possible after harvest; cool rooms with forced-air equipment will greatly speed the process and extend shelf life. Once fruit are precooled, hold them at 45° to 50°F with a relative humidity of 90 to 95 percent. Peppers suffer chilling injury when stored at temperatures below 40°F. Symptoms of chilling injury are browning at the calyx end and surface pitting. Peppers are usually packed in 1⅑ bushel waxed corrugated cartons (30 to 33 pounds) or in bushel crates (28 to 30 pounds) according to the preference of your particular market.

MARKETING CONTAINERS: *Peppers*

Pepper Type	Container Weight	Volume	No. Fruit/ Container
Long hot	30 lb	1 bu	variable
Jumbo bells	30 lb	1 ⅑ bu	40-45
Extra Large bells	30 lb	1 ⅑ bu	55-65
Large bells	30 lb	1 ⅑ bu	65-75
Medium bells	30 lb	1 ⅑ bu	75-90
Cubanelle	30-32 lb	1 ⅑ bu	variable
Specialty hot peppers[1]	16 lb	½ bu	variable

1 Including most of the small-fruited hot and specialty peppers in the "Varieties" table.

Tomato

Tomatoes are easily damaged and should be handled as carefully as possible in all picking, grading, packing, and hauling operations. Tomatoes should be grasped in the hand with the thumb and forefinger pressing against the stem, forcing the stem from the fruit.

When to harvest depends on what market you are growing for. "Vine-ripe" tomatoes that are to be shipped moderate distances are usually harvested at the "breaker" stage or at the "turning" stage. The breaker stage occurs when pink color first becomes noticeable, that is, when the white "star" at the blossom end of the fruit has turned pink, tannish-yellow, or red. In this case, 10 percent or less of the fruit surface shows the color change. Fruits harvested at the breaker stage can be handled and shipped with less damage than those with more color. "Turning" tomatoes are those with more than 10 percent but less than 30 percent of the fruit surface showing a color change from green to tannish-yellow, pink, or red.

Vine-ripe tomatoes must be harvested often (normally twice a week) to avoid having too many red fruit. Tomatoes for local markets should be harvested with much more color, according to customer preferences. Mature green tomatoes for distant markets are picked when the white "star" first appears on the blossom end. This indicates that seed are mature and that fruit will develop normal color when exposed to ethylene gas in a ripening room. Mature green tomatoes are normally harvested only three or four times during the season. Mature green tomatoes should be stored at 55° to 70°F and 85 to 90 percent relative humidity. Firm, ripe fruit should be stored at 45° to 50°F and 85 to 90 percent relative humidity.

All tomatoes must be sorted or graded before going to market. Tomatoes received at Kentucky's larger markets are often graded in the presence of a federal inspector. The USDA's Agricultural Marketing Service has established precise standards for grades of tomatoes. These are available on the Internet at ams.usda.gov/AMSv1.0/freshmarketvegetablestandards. Size classifications for both No. 1 and No. 2 grade tomatoes are shown in the table above (the USDA "small" category is not shown because there is little market for tomatoes of this size). Growers should be aware that some buyers may have their own size classifications that differ from these. "U.S. Combination" grade consists of a combination of Nos. 1 and 2, provided that at least 60 percent by count meet the requirements of No. 1 grade.

All grades must be free from decay, freezing injury, and sunscald and be reasonably well formed. No. 2 grade tomatoes differ from No. 1 grade in that they may be "slightly rough" and "reasonably well formed," whereas No. 1's must be "well formed" and "smooth." Some buyers will also consider fruits with 60 percent or more color a No. 2 grade.

Pack in the type and size container your market requires. Tomatoes are usually packed in 20 or 25 pounds cardboard cartons and are packed as tightly as possible without bruising. Packs must be of uniform size, color, and quality.

Growers should evaluate their marketing opportunities before the first seed is sown. Roadside stands, U-pick, delivery to local grocers, cooperatives, farmers' markets, and independent buyers are potential channels for selling produce. Contacts need to be made before planting. Beginners should consider the low-volume retail sales opportunities at farmers' markets or roadside stands. Large-scale production usually requires knowledge of wholesale marketing channels that can handle larger volumes of produce. Research at the University of Kentucky has shown that all marketing channels in the state are currently underused.

TOMATO SIZE CLASSES

The numbers in parentheses after each category indicate the number of rows and columns of fruit in a box: 6 x 7, for example indicates that in most cases a box of tomatoes in this size category will consist of an arrangement of 6 rows by 7 columns of fruits in one layer.

Size Class	Minimum Diameter[1] (in)	Maximum Diameter[2] (in)
Medium (6 x 7)	2 ¼	2 17/32
Large (6 x 6)	2 ½	2 25/32
Extra Large (5 x 5)	2 ¾ and above	
Maximum Large/Jumbo[3] (4 x 4 or 4 x 5)	3 ½ and above	

1 Will not pass through a round opening of this diameter when tomato is placed with its greatest traverse diameter across the opening.
2 Will pass through a round opening of this diameter in any position.
3 The USDA no longer lists the Maximum Large or Jumbo classification, however, many buyers require this size pack (4 x 4's or 4 x 5's). The old USDA Extra Large class had a range of 2 7/8 minimum to 3 15/32 maximum.

VARIETIES: Eggplant

Variety	DTM[1]	Comments
TRADITIONAL ITALIAN		
Nadia	62	Medium, teardrop shaped fruit, deep purple-black skin, soft spines; will set fruit in cool weather.
Epic	64	Good yield, strong upright plant; medium teardrop shaped fruit, deep purple/black, few spines.
Irene	65	Large broad fruit, high yield, purple/black, sharp spines.
Night Shadow	68	Medium sized, teardrop shaped, glossy purple/black, few soft spines.
Belen	70	Oval, medium sized purple/black, spineless.
Santana	80	Elongated oval shape, glossy purple/black, high yielding, green calyx, fewer spines.
ASIAN TYPE		
Orient Express	58	Elongated Oriental eggplant, sets fruit in cool and hot weather.
Dairyu	60	Long slim, purple/black fruit, few soft spines, Ichiban replacement.
Specialty		
Fairy Tale	55	Mini purple fruit with white strips, AAS winner.
Megal	60	Long tapered purple/black attractive fruit, few soft spines
Kermit	60	Small, round eggplant, green skinned
Nubia	64	Medium size, broad teardrop shape, dark wine streaks over cream background, sharp spines, very attractive
Little Fingers	66	Mini slender purple/black 6-inch long fruit; borne in clusters of 4 to 6 fruits.
Ghostbuster	80	White skinned, excellent flavor.

1 Days to Maturity

VARIETIES: Peppers

Variety	DTM[1]	Comments
BELL (ALL ARE F1 HYBRIDS AND HAVE RESISTANCE TO SEVERAL RACES OF BACTERIAL SPOT)		
Socrates	64	Race 1, 2, 3 resistant, PVY, early blocky fruits.
Declaration	70	Race 1, 2, 3, 5 resistant, intermediate resistance to *Phytophthora blight*, CMV, TSWV, high yields, little silvering.
Aristotle	70	Race 1, 2, 3 resistant, *Phytophthora* blight tolerant, slightly lighter fruit color, consistent producer from year to year.
Turnpike	72	Race 1-5 and 7-9 resistant, *Phytophthora* blight tolerant with TMV resistance; fruit have low silvering, dark green color and retain size very well all season.
Samuri S10	72	Race 1-10 intermediate resistance, Tobamovirus 0 resistant, very dark green uniformly shaped and sized fruit with very low silvering, good for early market.
Boca	73	Race 1-10 resistant, intermediate resistance to TSWV, very dark green thick walled fruit, good for early market.
Currier	73	Race 1-3 resistant, TMV, PVY 0, 1, 1-2, PepMoV, PepYMV, and intermediate resistance to CMV and *Phytophthora* blight. Blocky, large to extra-large fruit.
Sdy 48	73	Race 1-10 resistant, very dark green, large-jumbo fruit.
Green Flash	74	Race 1-10 intermediate resistance, dark green blocky X-large-jumbo fruit, attractive.
Alliance	74	Race 1, 2, 3, 5 resistant, PVY 0, 1, 1-2, TMV, PepMoV, Pep YMV with intermediate resistance to CMV, high yields, light to medium green fruit, little silvering..
Revolution	74	Race 1, 2, 3, 5 resistant, CMV and *Phytophthora blight* intermediate resistance, light to medium green fruit, may flatten in very hot weather.
PS 9928302	75	Race 1-5 resistant, TMV 1-3 resistant; very large to jumbo, dark green fruit.
Karisma	75	Race 1, 2, 3 intermediate resistance, resistant to TMV, PVY 0, 1, 1-2. Intermediate resistance to PepMoV, PepYMV, and CMV. Blocky, large to extra-large fruit.
Colored Bell		
Mavras	68	TMV, large blocky deep purple fruit (for trial).
Milena	70	Race 0, 1, 2, 3 resistant, PVY 0 intermediate resistance, TSWV intermediate resistance, orange fruit
Early Sunsation	70	Race 1, 2, 3 resistant, PVY tolerant, green to golden yellow, blocky.
SPECIALTY		
Cherry		
Cherry Bomb	68	High yielding, very hot; TMV resistance
Cherry Hot 102	70	Moderate heat level
Large Red Cherry	75	Very hot, 1¼ inch diameter fruits.
Pimento		
Pimento Elite (hybrid)	87	Heart-shaped, 3 x 3 inches, tapered.

(continued on next page)

VARIETIES: Peppers *(continued)*

Variety	DTM[1]	Comments
Jalapeño (all are F1 hybrids)		
Baluarte	71	Race 1, 2, 3 resistant; large fruit, low cracking
Tormenta	72	Race 1, 2, 3 resistant, TEV, large upright plant with thick fruit, average heat.
El Jefe	72	Bacterial spot resistant (races 1, 2, 3); dark green.
Banana and Wax		
Inferno	60-65	Hot banana, thick walled fruits, yellow and red.
Blazing Banana	60-70	Very hot; Race 1, 2, 3 resistant; thick walled
Hungarian Yellow Wax	65-70	Yellow to orange red, mildly hot, fruit 6 to 6.5 inches long, tapered.
Sweet Spot (X3R)	70	Race 1, 2, 3 resistant, banana, light yellow to red, 2 x 8 inches.
Italian/Cubanelle		
Aruba	65	High yielding, 2 x 7.5 inches, light green to pale yellow.
Corno di Toro	70-75	Light to medium green, 8 inches long, tapered, large plant, heirloom type from Italy.
Key West X3R	70-75	Light green, 2.5 x 7.5 inches, bacterial spot resistant (races 1, 2, 3).
Carmen	75	Green to red, fruit 7 inches long, AAS winner.
Poblano/Ancho		
San Ardo	75	Dark green to red, early and productive.
Tiburon	80	Dark green, 2.5 x 5.5 inches, high yields, sturdy plant.
Anaheim		
Anaheim TMR 23	75	Thick walled, 8 inches long, TMV tolerant.
Anaheim 118	75	Thick fleshed, light green to red
Serrano		
Serrano del Sol	70-72	High yielding and attractive fruits, 0.5 x 3.5 inches, tolerance to PMV and PVY.

1 Days to Maturity
Most of these have been tested at two or more locations by the University of Kentucky. We recommend that only bacterial spot resistant varieties be used. See "Common Diseases and Management" for more information on management of this important disease.

VARIETIES: Tomatoes—Fresh Market

Variety	DTM[1]	Comments
LARGE RED (ALL ARE DETERMINATE HYBRIDS)		
Defiant	67	High-yielding, mid-sized, globe shaped fruit. Disease resistance: Late blight, *Fusarium* race 1, 2, and *Verticillium*; Intermediate resistance: Early blight
Primo Red	68	Excellent vine ripe tomato for early plantings. Resistant to *Verticillium*, *Fusarium* race 1, 2, Tomato Mosaic Virus, and intermediate resistance to Tomato Spotted Wilt Virus. Crown set can have a pronounced, pointed blossom end. Performs well in high tunnel.
Red Deuce	71	Very large smooth fruit. Fruit size holds with average fruit weight 1 lb. Good for soilless production. Disease resistance: *Fusarium* race 1, 2, *Verticillium* race 1, Alternaria stem canker, Gray Leaf Spot.
Mountain Spring	72	Earliest of "Mountain" series; crack-resistant fruits; excellent for shipping. Spring and summer planting. Highly susceptible to Early blight. Disease resistance: *Fusarium* race 1, 2, *Verticillium* race 1
Phoenix	72	Good for later plantings, sets well in high temperatures. Disease resistance: Alternaria stem canker, *Fusarium* race 2, Verticillium Wilt 1
Amelia	75	Resistant to nematodes and intermediate resistance to tomato spotted wilt virus (TSWV). Disease resistance: *Fusarium* race 1, 2, 3, *Verticillium*, TSWV
Florida 47 R	75	Good yield and nice uniform 10-12 oz fruit. Disease resistance: Alternaria stem canker, *Fusarium* race 1, 2, *Verticillium* race 1, and gray leaf spot.
Rocky Top	76	Large smooth uniform fruit averaging 3/4 lb. Good for high tunnels production as well. Disease resistance: *Fusarium* race 1, 2, 3, and Gray Leaf Spot.
Mountain Fresh Plus	77	Crack-resistant fruit, mid-season; excellent flavor; for local sales or shipping. Disease resistance: *Fusarium* race 1, 2, *Verticillium* race 1, nematodes, Early blight tolerance
Red Defender	77	Good midseason variety, mostly large and extra-large fruits, uniform. Disease resistance: *Fusarium* race 1, 2, *Verticillium* race 1, TSWV, Alternaria stem canker
BHN 602	77	10-12 oz globe fruit with high yields good mid- and late-season tomato. Disease resistance: *Fusarium* race 1, 2, 3, *Verticillium* race 1, TSWV
BHN 589	75	8-10 oz. fruit. Plant is well-adapted to high tunnel growing conditions. High yield potential with large, deep red fruit. Excellent flavor and shelf life. Disease resistance: *Fusarium* wilt (races 1 and 2), TMV, and *Verticillium* wilt.

(continued on next page)

VARIETIES: Tomatoes—Fresh Market *(continued)*

Variety	DTM[1]	Comments
ROMA/PEAR/PASTE		
Pony Express	69	Concentrated early fruit set allows for short harvest window, 4 oz fruit, good performer in Kentucky. Disease resistance: *Fusarium* race 1, 2, 3, *Verticillium*, TMV, nematodes
Plum Crimson	80	Determinate hybrid; contains gene for early dark red interior color, high lycopene content, productive and Early blight tolerant. Disease resistance: *Fusarium* race 1, 2, 3, *Verticillium* race 1
Plum Regal	80	Pear/plum-shaped, high yielding variety, 4 oz. fruits. Disease resistance: *Fusarium* race 1, 2, *Verticillium*, TSWV, Late blight, Early blight
YELLOW/GOLD FRUIT		
Carolina Gold	72	Determinate; large, tangerine-colored, smooth, crack-resistant fruit for shipping or local sales. Early to midseason with resistance to gray wall; also excellent for fried green tomatoes. Tangerine color. Disease resistance: *Fusarium* race 1, 2, *Verticillium* race 1, susceptible to Early blight and bacterial leaf spot.
BHN 871	74	Determinate; large orange fruit, globe-shaped. Disease resistance: *Fusarium* race 1, 2, *Fusarium* crown and root rot, TMV, *Verticillium*.
GRAPE		
Golden Sweet	60	Indeterminate hybrid. Crack resistant, deep yellow fruit with mild flavor. Disease resistance: leaf mold, *Fusarium* wilt race 1.
Tami G	60	Indeterminate hybrid.½ to ¾ oz oval fruit, vigorous, yields well and picks for an extended season.
Smarty	68	Indeterminate hybrid. Compact plant, small 1⁄2 to 1 oz fruit. Disease resistance: *Fusarium* race 1, *Verticillium*
Mountain Honey	71	Semi-Indeterminate, ½-3/4 oz deep red fruit. Disease resistance: *Fusarium* race 3, Late blight, TSWV
CHERRY		
Sun Gold	57	Indeterminate hybrid. Bright orange, tendency to split. Disease resistance: *Fusarium* wilt, TMV.
Sun Sugar	62	½-3/4 oz yellow very sweet excellent flavored fruit, indeterminate plant. Disease resistance: *Fusarium* and TMV.
BHN 268	65-68	1 oz fruit, good shipper and shelf life. Disease resistance: *Fusarium* race 2, *Verticillium*
Sweet Chelsea	65	Indeterminate—1½ inch diameter very sweet fruit. Shipping and local sales. Disease resistance: *Fusarium* race 1, 2, *Verticillium*, Nematodes, TMV
Mountain Magic	72	Larger saladette type, indeterminate, excellent flavor. Disease resistance: *Fusarium* race 1, 2, Early blight, Late blight, *Verticillium*
HYDROPONIC		
Big Beef (see comments)	70	Not a true hydroponic variety, but successfully grown for spring-early summer hydroponic production, not for full season (10 month) production (yields decline after 6 months). Disease resistance: *Fusarium* race 2, *Verticillium*, Nematodes, Alternaria stem canker
Geronimo	78	Extremely vigorous plants, high yields, small stem scar, good performer. Disease resistance: *Fusarium* race 2, *Verticillium*, TMV
Bigdena	73	Large to extra-large fruit, uniform shape, good shelf life. Disease resistance: Leaf mold, *Fusarium* race 0, 1, ToMV, and TMV
Arbason	76	7-9 oz fruit with good yields and quality. Disease resistance: *Fusarium* race 1, 2, *Verticillium*, ToMV
INDETERMINATE, SPECIALTY, AND HEIRLOOM[2]		
Better Boy	72	Indeterminate, large fruit. On-farm and local sales only. Spring planting. Disease resistance: *Fusarium* race 1, *Verticillium*, Root-knot nematode
Lemon Boy	72	Yellow, indeterminate F1 hybrid for local sales; spring and summer planting. Disease resistance: *Verticillium* race 1, *Fusarium*, nematodes
Pink Girl	76	Hybrid, indeterminate. For local sales. Disease resistance: *Verticillium* race 1, *Fusarium* race 1
Delicious	77	Very large 1 1/2 to 2 1/2 lb fruit; solid red with small seed cavities; resists cracking.
San Marzano	78	Heirloom, indeterminate. Small oblong 5 to 6 oz fruit, meaty flesh, good for canning, high quality fruit. Disease resistance: *Fusarium* race 2, *Verticillium*
Mortgage Lifter	85	Heirloom, indeterminate. Large 1 lb fruit, pink, smooth and uniform in size, very meaty with few seeds; very heavy producer.
Arkansas Traveler	85	Heirloom, indeterminate. Medium 1/2 lb fruit, pink, smooth and uniform, good producer in hot weather.
Kentucky Beefsteak	90	Open-pollinated, indeterminate. Medium 1/2 lb fruit, yellow-orange with deep ridges at stem end; retains green shoulders on stem end when ripe.

(continued on next page)

VARIETIES: Tomatoes—Fresh Market *(continued)*

Variety	DTM[1]	Comments
Giant Belgium	90	Heirloom, indeterminate. Large 1 to 2 lb and larger fruit; solid dark pink flesh; very sweet; less cracking than other heirlooms; heavy producer.
German Johnson	80-90	Open-pollinated, indeterminate. Large-fruited "heirloom;" for local sales. Susceptible to cracking and roughness.
Big Rainbow	90-100	Heirloom, indeterminate. Large 1 to 2 lb fruit, meaty, golden orange-yellow with red stripes radiating from blossom end; prone to cracking.

1 Days to maturity

2"Heirloom" tomato varieties are popular for farm market and local sales. Growers should be aware that seed of some of these varieties may have become contaminated with TMV, clavibacter (canker), and Xanthomonas (bacterial spot), and should not be grown adjacent to plantings of other commercial varieties. Indeterminate varieties are best grown using wider in-row spacings of 24 to 36 inches and longer stakes (6 feet) or cages. UK trials of two popular varieties, "Brandywine" and "Cherokee Purple," have shown that fruit quality and appearance are highly variable from year to year; this variability likely stems from different seed sources. Growers are encouraged to test varieties from different sources before large-scale plantings.

FERTILIZER: Eggplant

Soil Test Results (lb/A)		Fertilizer Needed (lb/A)
Phosphorus		**Phosphate (P_2O_5)**
Low	<31	181-240
Medium	31-60	121-180
High	61-80	61-120
Very High	>80	0-60
Potassium		**Potash (K_2O)**
Low	<201	101-150
Medium	201-300	51-100
High	301-450	1-50
Very High	>450	0
Nitrogen		**N**

Apply 75 lb nitrogen (N)/A before transplanting. Broadcast and disk well with other fertilizer. Sidedress plants with 35 to 40 lb of N/A when first fruit appear. Too much N can delay fruiting and lead to large plants that fall over. See "Fertigation" table for N recommendations using plastic mulch and drip irrigation.

FERTILIZER: Peppers

Soil Test Results (lb/A)		Fertilizer Needed (lb/A)
Phosphorus		**Phosphate (P_2O_5)**
Low	<31	81-100
Medium	31-60	61-80
High	61-80	1-60
Very High	>80	0
Potassium		**Potash (K_2O)**
Low	<201	81-100
Medium	201-300	61-80
High	301-450	1-60
Very High	>450	0
Nitrogen		**N**

Peppers use approximately 100 to 150 lb of N/A. Apply 25 to 50 lb of N/A preplant. Rate to use will vary depending on previous crop and general fertility of the soil. Following sod, apply 50 lb of N/A prior to planting. After fruit begin setting, sidedress with another 30 to 50 lb of N/A. Two weeks later, make an additional application of 30 to 50 lb of N/A. For N fertigation, see comments in text and specific recommendations in the "Fertigation" table.

FERTILIZER: Tomatoes

The following fertilizer rates are to be used only as guidelines. Research at the University of Kentucky and at the University of Tennessee indicates that there is no yield increase from using more than 60 lb/A of P_2O_5 when soil test P levels are high.

Soil Test Results (lb/A)		Fertilizer Needed (lb/A)
Phosphorus		**Phosphate (P_2O_5)**
Low	<31	181-240
Medium	31-60	61-180
High	61-80	1-60
Very High	>80	0
Potassium		**Potash (K_2O)**
Low	<201	121-250
Medium	201-300	61-120
High	301-450	1-60
Very High	>450	0
Basal nitrogen where tomatoes:		**N**
1. follow grass-legume or legume sod		30
2. follow grass sod		50
3. are grown on continually cropped land		60

Supplemental applications: On bare ground plantings, apply an additional 30 lb of N/A as a sidedressing when the first fruits are golf-ball size. A second sidedress application of 30 lb N/A may also be desirable two or three weeks later, depending on the crop's growing condition. For plasticulture with drip on medium-textured soils, apply all recommended phosphorus and potassium requirements prior to laying plastic mulch. See "Fertigation" table for N application rates.

FERTIGATION: Eggplant[1]

Actual N/week:	6 lb/A
Calcium Nitrate	38 lb 11 oz/A 8 lb 14 oz/1,000 plants

Total amount/season: 120 lb/A

Preplant amount: 60 lb/A

Fertigated amount: 60 lb/A

Growing season: 10 weeks

Fertigation can begin 10 to 14 days after transplanting.

The doses listed for 1,000 plants are based on a plant population of 4,356 plants/A (i.e., rows on 5 foot centers and plants 24 inches apart).

For seasons extending beyond 10 weeks from transplanting, a maintenance dose of 1 to 1.5 lb N/week/A (6.5 to 9.7 lb calcium nitrate) is adequate.

1 All recommendations assume starter fertilizer was used.

FERTIGATION: Bell Peppers[1]

Moderate Rate

Actual N/week:	6 lb 4 oz/A
Calcium Nitrate	40 lb/A 3 lb/1,000 plants

High Rate

Actual N/week:	8 lb 5 oz/A
Calcium Nitrate	54 lb/A 4 lb/1,000 plants

Total amount/season: 125 lb/A (moderate rate)

150 lb/A (high rate)

Preplant amount: 50 lb/A

Fertigated amount: 75 lb/A (moderate rate)

100 lb/A (high rate)

Growing season: 12 weeks

Fertigation should begin about 2 weeks after transplanting.

The dose for 1,000 plants is based on a plant population of 14,500 plants/A (i.e., double rows on 6 foot centers with plants 12 inches apart in the rows).

For seasons extending beyond 12 weeks, a maintenance dose of 1 to 1.5 lb N/A/week is adequate

1 All recommendations assume starter fertilizer was used.

FERTIGATION: Staked Tomatoes[1]

Moderate Rate

Actual N/week:	7 lb 8 oz/A
Calcium Nitrate	48 lb 6 oz/A 11 lb 8 oz/1,000 plants

High Rate

Actual N/week:	10 lb/A
Calcium Nitrate	64 lb 8 oz/A 15 lb 6 oz/1,000 plants

AT-RISK SITES

Moderate Rate

Actual N/week:	7 lb 8 oz/A
Potassium Nitrate	57 lb 11 oz/A 13 lb 12 oz/1,000 plants
Potassium Nitrate: K provided	25 lb 6 oz/A 6 lb 1 oz/1,000 plants

High Rate

Actual N/week:	10 lb/A
Potassium Nitrate	76 lb 15 oz/A 18 lb 5 oz/1,000 plants
Potassium Nitrate: K provided	33 lb 14 oz/A 8 lb 1 oz/1,000 plants

Total amount/season: 125 lb/A (moderate rate)

150 lb/A (high rate)

Preplant amount: 50 lb/A

Fertigated amount: 75 lb/A (moderate rate)

100 lb/A (high rate)

Growing season: 10 weeks

Fertigation can begin 10 to 14 days after transplanting.

The doses for 1,000 plants are based on a plant population of 4,200 plants/A (i.e., rows on 6 foot centers in 5-row blocks and plants 18 inches apart).

For harvest seasons extending beyond 10 weeks from transplanting, a maintenance dose of 1 to 1.5 N (6.5 to 9.7 lbs of calcium nitrate, or 11.5 lbs of potassium nitrate for "at risk" sites) per week is adequate.

IMPORTANT: If growing tomatoes, be sure to enter "tomato" into the "Crop to be Grown" category on your soil test. UK soil testing will provide you with a Hartz ratio that will indicate if your plants may be at risk for ripening disorders. Potassium nitrate supplies both nitrogen and potassium and can be used as a substitute for calcium nitrate.

1 All recommendations assume starter fertilizer was used.

PESTICIDE SAFETY: Eggplant, Peppers, and Tomatoes

	Signal[1]	Re-entry (hrs)	Harvest (days)
INSECTICIDES			
Acramite 50 WS	C	12	3
Actara 25 W	C	12	0
Admire Pro	C	12	0/21[4]
Assail 30 SG	C	12	7
Avaunt eVo 30 DG	C	12	3
Azera	C	12	0
Belay 50 WDG	C	12	7/AP
Beleaf 50 SG	C	12	0
Bt products	C	4/12	0
Coragen 1.67 SC	-	4	1
Courier 40 SC	W	12	1
Dimethoate 4 E	W	48	7
Entrust 2 SC	C	4	1
Exirel 0.83 SE	C	21	1
Fulfill 50 DF	C	12	0
Grandevo 30 W	C	12	1
Harvanta 50 SL	C	4	1
Intrepid 2 F	C	4	1
Kanemite 15 SC	C	12	1
Knack 0.86 EC	C	12	1
Magister SC	W	12	3
Malathion 8	C	12	1/3[4]
Miteus 0.42 EC	W	12	1
Movento 2	C	24	1
Nealta 1.67 SC[2]	C	12	3
Oberon 2 SC	C	12	1
Orthene 97 S[2]	C	24	7
Platinum 2 SC	C	12	30
Portal 0.4 EC	W	12	1
PQZ 1.87 SC	C	12	1
Pyganic 5 EC	C	12	0
Pylon 0.5 EC	C	12	0
Radiant SC	C	4	1
Requiem 25 EC	C	4	0
Rimon 0.83 EC	W	12	1
Scorpion 3.5 SL	C	12	1/21[4]
Sefina 0.42 SC	C	12	0
Sevin XLR Plus	W	12	3
Sivanto Prime 1.67 SL	C	12	1/45[4]
Torac 1.29 EC	W	12	1
Transform 50 WG	D	24	1
Trident	C	4	0

(continued)

PESTICIDE SAFETY: Eggplant, Peppers, and Tomatoes *(continued)*

	Signal[1]	Re-entry (hrs)	Harvest (days)
Trigard 75 WP	C	12	0
Venom 70 SG	C	12	1/21[4]
Verimark 1.67 SC	-	4	1
Zeal 72 WP[2]	C	12	7
Restricted Use			
AgriMek 0.7 SC	W	12	7
Asana XL	W	12	1
Baythroid XL	W	12	0/7[4]
Brigade 2 EC	W	12	1/7[4]
Danitol 2.4 EC	W	24	3
Diazinon AG 500[2]	C	24	1
Diazinon 50 W[2]	C	24	1
Fastac 0.83 EC	D	12	1
Lannate 90 SP	DP	48	1/3/5[4]
Mustang Maxx	W	12	1
Permethrin 3.2 EC	C	12	0/3[4]
Proaxis 0.5 EC	C	24	5
Proclaim 5 WDG	C	48	7
Vydate L	DP	48	3
Warrior II	W	24	5
FUNGICIDES			
Actigard 50 WG	C	12	14
Aprovia Top	W	12	0
Ariston	C	12	3
Azoxystrobin[3]	C	4	0
Blocker 4F	C	12	0
Botran 75 W	C	12	10
Cabrio EG	C	12	0
Chlorothalonil[3]	D	12	0
Fixed coppers[3]	D	24/48[5]	0
Curzate 60 DF	W	12	3
Dexter Max	C	24	5
Dexter XCEL	C	24	7
Endura	W	12	0
Fluoxastrobin[3]	C	12	3
Fontelis	C	12	0
Forum	C	12	4
Fracture	C	4	0
Gavel 75 DF	C	48	3
Inspire Super	C	12	0
Luna Sensation	C	12	3
Luna Tranquility	C	12	1
Mancozeb[3]	C	24	5
ManKocide	D	24	5

(continued)

PESTICIDE SAFETY: Eggplant, Peppers, and Tomatoes *(continued)*

	Signal[1]	Re-entry (hrs)	Harvest (days)
Mandipropamid[3]	C	4	1
Mefenoxam[3]	C/W	48	7/28
Metalaxyl[3]	W	48	28
Miravis Prime	C	12	0
Orondis Gold 200	C	4	0
Orondis Opti	D	12	0
Orondis Ultra	C	4	1
Presidio	C	12	2
Previcur Flex	C	12	5
Priaxor	C	12	7
Pyraclostrobin[3]	C	12	0
Quadris Opti	W	12	0
Quadris Top	C	12	0
Rally 40 WSP	W	24	0
Ranman	C	12	0
Reason 500 SC	C	12	14
Revus Top	C	12	1
Rhyme	W	12	0
Ridomil Gold Bravo SC	W	48	14
Ridomil Gold Copper	D	48	14
Ridomil Gold MZ	C	48	5
Scala	C	12	1
Streptomycin[3]	C	12	n/a
Switch 62.5 WG	C	12	0
Tanos	C	12	3
Trifloxystrobin[3]	C	12	3
Topguard	C	12	0
Torac	W	12	1
Torino	C	12	0
Velum	C	12	7
Vivando	C	12	0
Zampro	C	12	4
Zing!	C	12	5
Ziram[3]	D	48	7

1 W: Warning, C: Caution, D: Danger; P: Poison
2 Not all insecticides can be used on all listed crops. Check labels carefully.
3 Several formulations are marketed. See the general introduction for more details on fungicides.
4 Dependent on crop, application rates and types see label.
5 Varies by formulation; consult labels carefully.

INSECT CONTROL: Fruiting Vegetables - Eggplant, Peppers,Tomatoes[1,2]

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Soil Application			
Aphids, Flea Beetles, Colorado Potato Beetle: Do not use foliar sprays of Actara, Assail, Belay, Provado, or Venom following soil applications of Admire, Belay, Platinum, or Venom.			
Admire Pro	7 to 14 fl oz	14 fl oz	See label for application methods. Use lower rate (10.5) for tomato and eggplant.
Belay 50 WDG	4.8 to 6.4 oz	6.4 oz	Apply at planting.
Coragen 1.67 SC	3.5 to 7.5 fl oz	15.4 fl oz	Soil and foliar applications possible for CPB. See label for limitations.
Platinum 2 SC	5 to 11 fl oz	11 fl oz	See label for application alternatives. Also, helps to control thrips.
Sivanto Prime 1.67 SL	21 to 28 fl oz	28 fl oz	For aphids and whiteflies.
Venom 70 SG	5 to 7.5 oz	12 oz	
Verimark 1.67 SC	6.75 to 13.5 fl oz	13.5 or 31.5 fl oz	At planting or through dripline.
Foliar Application			
Aphids: Treat if aphids are found on 50% of leaves.			
Actara 25 WDG	2 to 3 oz	11 oz	Allow 5 days between applications. Not during bloom. Field use only.
Admire Pro	1.3 to 2.2 fl oz	6.7 fl oz	Allow 5 days between applications. Not during bloom.
Assail 30 SG	2 to 4 oz	16 oz	Limit 4 applications. Allow 7 days between applications.
Belay 50 WDG	1.6 to 2.1 oz	6.4 oz	Allow 10 days between applications.
Beleaf 50 WDG	2.8 to 4.28 oz	8.4 oz	Allow 7 days between applications.
Dimethoate 4 E	8 to 16 fl oz	16 fl oz	Allow 6 days between applications. Not for use on eggplant, use lower rate for peppers.
Exirel 0.83 SE	13.5 to 20.5 fl oz	61.5 fl oz	Allow 5 days between applications.
Fulfill 50 DF	2.75 oz	5.5 oz	Allow 7 days between applications.
Lannate 90 SP	0.25 to 1 lb	4, 5 or 7 lb	Limit 8, 10 or 16 applications. Total use depends on crop treated.
Malathion 8	1.5 pt	2 or 4 applications	Allow 5 days between applications. Application limits depend on crop treated.
Movento 2 SC	4 to 5 fl oz	10 fl oz	Allow 7 days between applications. Field use only. Requires surfactant.
PQZ 1.87 SC	2.4 to 3.2 fl oz	4.8 fl oz	Limit 2 applications. Allow 7 days between applications.
Sefina 0.42 SC	3 fl oz	28 fl oz	Allow 7 days between applications.
Sivanto Prime 1.67 SL	7 to 14 fl oz	28 fl oz	Allow 7 days between applications.
Torac 1.29 EC	17 to 21 fl oz	42 fl oz	Limit 2 applications. Allow 14 days between applications.
Transform 50 WG	0.75 to 1 oz	8.5 oz	Allow 7 days between applications. Limit 4 applications.
Beet Armyworm: First detected in Kentucky in 1993, this insect can cause serious losses to pepper and tomato when present. Large larvae are difficult to control effectively with insecticides.			
Avaunt eVo	3.5 to 6 oz	24 oz	Allow 5 days between applications. Limit 4 applications.
Coragen 1.67 SC	3.5 to 7.5 fl oz	15.4 fl oz	Soil and foliar applications possible. See label for limitations.
Exirel 0.83 SE	7 to 13.5 fl oz	61.5 fl oz	Allow 5 days between applications.
Harvanta 50 SL	10.9 to 16.4 fl oz	49.2 fl oz	Allow 7 days between applications.
Intrepid 2 F	4 to 16 fl oz	64 fl oz	Allow 7 days between applications. Limit 4 applications.
Proclaim 5 WDG	2.4 to 4.8 oz	14.4 oz	Allow 7 days between applications.
Pylon 0.125	6.5 to 13 fl oz	39 fl oz	Allow 5 days between applications. For greenhouse use only.
Radiant SC	5 to 10 fl oz	34 fl oz	Allow 4 days between applications.
Rimon 0.83 EC	9 to 12 fl oz	36 fl oz	Allow 7 days between applications.
Colorado Potato Beetle: This is a pest of tomato transplants and eggplant. This pest has the ability to develop resistance to all major classes of insecticides. Do not tank-mix insecticides with the same mode of action and frequently rotate among insecticides with different modes of action to discourage resistance. Treat for Colorado potato beetle if an average of 1 adult larva or egg mass per plant is found and plants are less than 12 inches tall (staked). IRAC Codes: Insecticides followed by the same number share the same mode of action.			
Actara 25 W (4A)	2 to 3 oz	11 oz	Allow 5 days between applications. Not during bloom.
Admire Pro (4A)	1.3 to 2.2 fl oz	6.7 fl oz	Allow 5 days between applications. Not during bloom.
AgriMek 0.7 SC (6)	1.75 to 3.5 fl oz	10.25 fl oz	Allow 7 days between applications. Must use non-ionic surfactant.
Assail 30 SG (4A)	1.5 to 2.5 oz	16 oz	Limit 4 applications. Allow 7 days between applications.

(continued on next page)

INSECT CONTROL: Fruiting Vegetables - Eggplant, Peppers,Tomatoes[1,2] *(continued)*

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Belay 50 WDG (4A)	1.6 to 2.1 oz	6.4 oz	Allow 10 days between applications.
Coragen 1.67 SC (28)	3.5 to 7.5 fl oz	15.4 fl oz	Soil and foliar applications possible. See label for limitations.
Exirel 0.83 SE (28)	7 to 13.5 fl oz	61.5 fl oz	Allow 5 days between applications.
Harvanta 50 SL (28)	10.9 to 16.4 fl oz	49.2 fl oz	Allow 7 days between applications.
Radiant SC (5)	5 to 10 fl oz	34 fl oz	Allow 4 days between applications.
Rimon 0.83 EC (15)	9 to 12 fl oz	36 fl oz	Allow 7 days between applications.
Sivanto Prime 1.67 SL (4D)	10.5 to 14 fl oz	28 fl oz	Allow 7 days between applications.
Torac 1.29 EC (21A)	14 to 21 fl oz	42 fl oz	Limit 2 applications. Allow 14 days between applications.
Trident (11A)	3 to 6 qt	-	-
Venom 70 SG (4A)	1 to 4 oz	6 oz	For foliar applications.
Cutworms: Eliminate weeds from field margins and plow fields at least 2 weeks before planting to destroy cutworm food sources and egg laying sites.			
Asana XL	5.8 to 9.6 fl oz	67 or 96 fl oz	Allow 7 days between applications. For cutworm control on tomato only.
Brigade 2 E	2.1 to 5.2 or 6.4 fl oz	12.8 or 25.6 fl oz	Allow 7 or 10 days between applications. Rate and application limitations depend on crop.
Fastac 0.83 EC	2.2 to 3.8 fl oz	11.4 fl oz	Allow 7 days between applications.
Mustang Maxx	2.24 to 4 fl oz	24 fl oz	Allow 7 days between applications.
Proaxis 0.5 EC	1.92 to 3.2 fl oz	46 fl oz	Allow 5 days between applications.
Sevin XLR Plus	2 qt	8 qt	Limit 7 applications. Allow 7 days between applications.
Warrior II	0.96 to 1.6 fl oz	23 fl oz	Allow 5 days between applications.
European Corn Borer: Key insect pest of peppers. Use pheromone traps to monitor for adult activity. Begin applications when trap catches or moths exceed 10 moths per week.			
Asana XL	5.8 to 9.6 fl oz	67.2 fl oz	Allow 7 days between applications.
Baythroid XL	1.6 to 2.8 fl oz	16.8 fl oz	Allow 7 days between applications.
Brigade 2 E	2.1 to 6.4 fl oz	12.8 fl oz	Allow 7 days between applications.
Coragen 1.67 SC	3.5 to 7.5 fl oz	15.4 fl oz	Foliar, drip, and soil applications possible. See label for limitations.
Exirel 0.83 SE	7 to 13.5 fl oz	61.5 fl oz	Allow 5 days between applications. Use an adjuvant.
Fastac 0.83 EC	2.2 to 3.8 fl oz	11.4 fl oz	Allow 7 days between applications.
Harvanta 50 SL	10.9 to 16.4 fl oz	49.2 fl oz	Allow 7 days between applications.
Intrepid 2 F	4 to 16 fl oz	64 fl oz	Limit 4 applcations. Allow 7 days between applicatrions.
Mustang Maxx	2.24 to 4 fl oz	24 fl oz	Allow 7 days between applications.
Orthene 97 S	0.75 to 1 lb	2.12 lb	Bell peppers only. Allow 3 days between applications.
Permethrin 3.2 EC	8 fl oz	32 fl oz	Bell peppers only. Allow 5 days between applications.
Proaxis 0.5 EC	2.56 to 3.84 fl oz	46 fl oz	Allow 5 days between applications.
Radiant SC	5 to 10 fl oz	34 fl oz	Allow 4 days between applications.
Rimon 0.83 EC	9 to 12 fl oz	36 fl oz	Allow 7 days between applications.
Sevin XLR Plus	1 to 2 qt	8 qt	Limit 7 applications. Allow 7 days between applications.
Warrior II	1.28 to 1.92 fl oz	23 fl oz	Allow 5 days between applications.
Fruitworms: Pests of pepper and tomato. Carefully monitor plants for eggs on undersides of leaves, often near flower clusters. Treat if an average of more than 1 egg or larvae per 40 plants is found.			
Asana XL	5.8 to 9.6 fl oz	67 or 96 fl oz	Allow 7 days between applications.
Avaunt eVo	3.5 to 6 oz	24 oz	Allow 5 days between applications. Limit 4 applications.
Baythroid XL	1.6 to 2.8 fl oz	16.8 fl oz	Allow 7 days between applications.
Brigade 2 E	2.1 to 5.2 or 6.4 fl oz	12.8 or 25.6 fl oz	Allow 7 or 10 days between applications. Rate and application limitations depend on crop.
Coragen 1.67 SC	3.5 to 7.5 fl oz	15.4 fl oz	Soil and foliar applications possible. See label for limitations.
Danitol 2.4 EC	10.67 fl oz	42.6 fl oz	Allow 7 days between applications.
Fastac 0.83 EC	2.2 to 3.8 fl oz	11.4 fl oz	Allow 7 days between applications.
Harvanta 50 SL	10.9 to 16.4 fl oz	49.2 fl oz	Allow 7 days between applications.
Lannate 90 SP	0.5 to 1 lb	5 or 7 lb	Limit 10 or 16 applications. Not for fruitworms on peppers. Application limitations depend on crop.
Mustang Maxx	2.24 to 4 fl oz	24 fl oz	Allow 7 days between applications.
Permethrin 3.2 EC	2 to 8 fl oz	24 or 32 fl oz	Not for use on cherry tomatoes. Allow 5 or 7 days between applications. Application limitations depend on crop.

(continued on next page)

INSECT CONTROL: Fruiting Vegetables - Eggplant, Peppers,Tomatoes[1,2] *(continued)*

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Proaxis 0.5 EC	2.56 to 3.84 fl oz	46 fl oz	Allow 5 days between applications.
Radiant SC	5 to 10 fl oz	34 fl oz	Allow 4 days between applications.
Rimon 0.83 EC	9 to 12 fl oz	36 fl oz	Allow 7 days between applications.
Sevin XLR Plus	1 to 2 qt	8 qt	Limit 7 applications. Allow 7 days between applications.
Warrior II	1.28 to 1.92 fl oz	23 fl oz	Allow 5 days between applications.
Grasshoppers			
Asana XL	5.8 to 9.6 fl oz	96 fl oz	Allow 7 days between applications. For hornworm control on tomato only.
Brigade 2 E	2.1 to 5.2 fl oz	25.6 fl oz	Allow 10 days between sprays. For grasshopper control on tomato.
Fastac 0.83 EC	3.2 to 3.8 fl oz	11.4 fl oz	Allow 7 days between applications.
Mustang Maxx	3.2 to 4 fl oz	24 fl oz	Allow 7 days between applications.
Proaxis 0.5 EC	2.56 to 3.84 fl oz	46 fl oz	Allow 5 days between applications.
Warrior II	1.28 to 1.92 fl oz	23 fl oz	Allow 5 days between applications.
Hornworms: A pest of tomato. Treat if an average of more than 1 hornworm per 5 plants is found.			
Asana XL	2.9 to 5.8 fl oz	67 or 96 fl oz	-Allow 7 days between applications. For grasshopper control on tomato.
Avaunt eVo	2.5 to 6 oz	24 oz	Allow 5 days between applications. Limit 4 applications.
Baythroid XL	1.6 to 2.8 fl oz	16.8 fl oz	Allow 7 days between applications.
Bt var kurstaki products	See labels	-	-
Coragen 1.67 SC	2 to 5 fl oz	15.4 fl oz	Soil and foliar applications possible. See label for limitations.
Fastac 0.83 EC	2.2 to 3.8 fl oz	11.4 fl oz	Allow 7 days between applications.
Harvanta 50 SL	10.9 to 16.4 fl oz	49.2 fl oz	Allow 7 days between applications.
Intrepid 2 F	4 to 16 fl oz	64 fl oz	Allow 7 days between applications. Limit 4 applications.
Lannate 90 SP	0.5 to 1 lb	7 lb	Limit 16 applications. For hornworm control on tomato.
Mustang Maxx	2.24 to 4 fl oz	24 fl oz	Allow 7 days between applications.
Permethrin 3.2 EC	2 to 8 fl oz	24 fl oz	Allow 7 days between applications. For hornworm control on tomato varieties over 1 inch in diameter.
Proaxis 0.5 EC	1.92 to 3.2 fl oz	46 fl oz	Allow 5 days between applications.
Radiant SC	5 to 10 fl oz	34 fl oz	Allow 4 days between applications.
Rimon 0.83 EC	9 to 12 fl oz	36 fl oz	Allow 7 days between applications.
Sevin XLR Plus	1 to 2 qt	8 qt	Limit 7 applications. Allow 7 days between applications.
Warrior II	0.96 to 1.6 fl oz	23 fl oz	Allow 5 days between applications.
Flea Beetles: Maintain defoliation below 5 to 10%.			
Asana XL	5.8 to 9.6 fl oz	67 or 96 fl oz	Allow 7 days between applications. Limitations based on crop treated.
Belay 50 WDG	1.6 to 2.1 oz	6.4 oz	Allow 10 days between applications.
Brigade 2 E	2.1 to 5.2 or 6.4 fl oz	12.8 or 25.6 fl oz	Allow 10 days between applications. Limit 2 or 4 applications. Limitations based on crop treated.
Danitol 2.4 EC	10.67 fl oz		
Fastac 0.83 EC	2.2 to 3.8 fl oz	11.4 fl oz	Allow 7 days between applications.
Mustang Maxx	2.24 to 4 fl oz	24 fl oz	Allow 7 days between applications.
Proaxis 0.5 EC	2.56 to 3.84 fl oz	46 fl oz	Allow 5 days between applications.
Scorpion 35 SL	2 to 7 fl oz	10.5 fl oz	Allow 7 days between applications.
Sevin XLR Plus	0.5 to 1 qt	8 qt	Limit 7 applications. Allow 7 days between applications.
Torac 1.29 EC	17 to 21 fl oz	42 fl oz	Limit 2 applications. Allow 14 days between applications.
Venom 70 SG	1 to 4 oz	6 oz	Allow 7 days between applications.
Warrior II	1.28 to 1.6 fl oz	23 fl oz	Allow 5 days between applications.
Mites			
Acramite 50 WS	0.75 to 1 lb	1 application	For spider mites.
AgriMek 0.7 SC	1.75 to 3.5 fl oz	10.25 fl oz	Allow 7 days between applications. For broad, russet, and spider mites. Must use non-ionic surfactant.
Brigade 2 E	2.1 to 5.2 fl oz	12.8 or 25.6 fl oz	Allow 10 days between applications. For end of season control. For spider mites only. Limit 2 or 4 applications. Limitations based on crop treated.
Danitol 2.4 EC	10.67 fl oz	42.6 fl oz	Allow 7 days between applications. For end-of-season control. For spider mites only.

(continued on next page)

INSECT CONTROL: Fruiting Vegetables - Eggplant, Peppers,Tomatoes[1,2] *(continued)*

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Kanemite 15 SC	31 fl oz	62 fl oz	Allow 21 days between applications. For spider and broad mites.
Magister 1.7 SC	24 to 36 fl oz	36 fl oz	Limit 1 application. For spider and broad mites.
Miteus 0.42 EC	2 pt	4 pt	Allow 14 days between applications. Limit 2 applications.
Movento 2 SC	4 to 5 fl oz	10 fl oz	For broad and russett mites. Allow 7 days between applications. Requires surfactant.
Nealta 1.67 SC	13.7 fl oz	27.4 fl oz	Allow 14 days between applications. For spider mites only. Limit 2 applications. For tomato only.
Oberon 2 SC	7 to 8.5 fl oz	25.5 fl oz	Limit 3 applications. For broad, russett, and spider mites.
Portal 0.4 EC	2 pt	4 pt	Limit 2 applications. For broad, russett, and spider mites. Allow 14 days between applications.
Torac 1.29 EC	14 to 21 fl oz	42 fl oz	Limit 2 applications. Allow 14 days between applications. For broad mite only.
Stink Bugs, Leaf-footed Bugs: Treat if an average of more than 1 stink bug per 40 plants or 0.75% damaged fruit is found.			
Actara 25 WDG	3 to 5.5 oz	11 oz	Allow 5 days between applications. Not during bloom.
Baythroid XL	1.6 to 2.8 fl oz	16.8 fl oz	Allow 7 days between applications.
Belay 50 WDG	1.6 to 2.1 oz	6.4 oz	Allow 10 days between applications.
Brigade 2 E	2.1 to 5.2 or 6.4 fl oz	12.8 or 25.6 fl oz	Allow 7 or 10 days between applications. Limit 2 or 4 applications. Limitations based on crop treated.
Danitol 2.4 EC	10.67 to 16 fl oz	42.6 fl oz	Allow 7 days between applications.
Fastac 0.83 Ec	2.2 to 3.8 fl oz	11.4 fl oz	Allow 7 days between applications.
Mustang Maxx	3.2 to 4 fl oz	24 fl oz	Allow 7 days between applications.
Proaxis 0.5 EC	2.56 to 3.84 fl oz	46 fl oz	Allow 5 days between applications.
Rimon 0.83 EC	12 fl oz	36 fl oz	Allow 7 days between applications. For immature control only.
Scorpion 35 SL	2 to 7 fl oz	10.5 fl oz	Allow 7 days between applications.
Warrior II	1.28 to 1.92 fl oz	23 fl oz	Allow 5 days between applications.
Thrips			
Assail 30 SG	4 oz	16 oz	Allow 7 days between applications.
Baythoid XL	2.1 to 2.8 fl oz	16.8 fl oz	Allow 7 days between applications.
Brigade 2 E	2.1 to 5.2 or 6.4 fl oz	12.8 or 25.6 fl oz	Allow 7 or 10 days between applications. . Limit 2 or 4 applications. Limitations based on crop treated.
Radiant SC	6 to 10 fl oz	34 fl oz	Allow 4 days between applications.
Requiem EC	2 to 4 qt	-	-
Rimon 0.83 EC	12 fl oz	36 fl oz	Allow 7 days between applications. For immature control only.
Scorpion 35 SL	2 to 7 fl oz	10.5 fl oz	Allow 7 days between applications.
Torac 1.29 EC	21 fl oz	42 fl oz	Limit 2 applications. Allow 14 days between applications.
Venom 70 SG	1 to 4 oz	6 oz	Allow 7 days between applications.
Whiteflies			
Actara 25 WDG	3.0 to 5.5 oz	11 oz	Allow 5 days between applications. Not during bloom.
Admire Pro	1.3 to 2.2 fl oz	6.7 fl oz	Allow 5 days between applications. Not during bloom.
Assail 30 SG	2.5 to 4 oz	16 oz	Limit 4 applications. Allow 7 days between applications.
Exirel 0.83 SE	13.5 to 20.5 fl oz	61.5 fl oz	Allow 5 days between applications. Use a spray adjuvant.
Fulfill 50 DF	2.75 oz	5.5 oz	Allow 7 days between applications.
Knack 0.86 EC	8 to 10 fl oz	16 fl oz	Allow 14 days between applications. Limit 2 applications.
Movento 2 SC	4 to 5 fl oz	10 fl oz	Allow 7 days between applications. Requires surfactant.
Oberon 2 SC	7 to 8.5 fl oz	25.5 fl oz	Limit 3 applications.
PQZ 1.87 SC	2.4 to 3.2 fl oz	4.8 fl oz	Limit 2 applications. Allow 7 days between applications.
Portal 0.4 EC	2 pt	4 pt	Limit 2 applications. Allow 14 days between applications.
Requiem EC	2 to 3 qt	-	-
Rimon 0.83 EC	12 fl oz	36 fl oz	Allow 7 days between applications. For immature control only.
Scorpion 35 SL	2 to 7 fl oz	10.5 fl oz	Allow 7 days between applications.
Sefina 0.42 SC	14 fl oz	28 fl oz	Allow 7 days between appications.
Sivanto Prime 1.67 SL	10.5 to 14 fl oz	28 fl oz	Allow 7 days between applications.
Venom 70 SG	1 to 4 oz	6 oz	Allow 7 days between applications.

INSECT CONTROL: Greenhouse/High Tunnel Grown Eggplant, Pepper and Tomatoes[1,2]

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Mites: Two spotted spider mite, broad mite, and tomato russett mite			
Acramite 50 WS	0.75 to 1 lb	1 lb	For spider mites only. Limit 1 application.
AgriMek 0.7 SC	1.75 to 3.5 fl oz	10.25 fl oz	Allow 7 days between applications. For russett and spider mites. Must use non-ionic surfactant. Only for tomatoes in greenhouses.
Brigade 2 E	2.1 to 5.2 fl oz	12.8 to 25.6 fl oz	Allow 7 or 10 days between applications. For end of season control. For spider mites only. Limit 2 or 4 applications. Limitations based on crop treated.
Danitol 2.4 EC	10.67 fl oz	42.6 fl oz	Allow 7 days between applications. For end-of-season control. For spider mites only.
Kanemite 15 SC	31 fl oz	62 fl oz	Allow 21 days between applications. For spider mites only.
Magister SC	24 to 36 fl oz	36 fl oz	Limit 1 application. For spider and broad mites.
Oberon 2 SC	7 to 8.5 fl oz	25.5 fl oz	Limit 3 applications. For broad, russett, and spider mites.
Portal 0.4 EC	2 pt	4 pt	Limit 2 applications. For broad, russett, and spider mites. Allow 14 days between applications.
Pylon 2 SC	6.5 to 13 fl oz	39 fl oz	Allow 5 days between applications. For spider and broad mites. Only for tomato varieties with fruit > 1 inch. Can be used on peppers and eggplant.
Thrips			
Assail 30 SG	4 oz	16 oz	Allow 7 days between applications.
Baythoid XL	2.1 to 2.8 fl oz	16.8 fl oz	Allow 7 days between applications.
Brigade 2 E	2.1 to 5.2 or 6.4 fl oz	12.8 or 25.6 fl oz	Allow 7 or 10 days between applications. Limit 2 or 4 applications. Limitations based on crop treated.
Exirel 0.83 SE	13.5 to 20.5 fl oz	61.5 fl oz	Allow 5 days between applications. Use a spray adjuvant. For foliar feeding thrips.
Pylon 2 SC	9.8 to 13 fl oz	39 fl oz	Allow 5 days between applications. Only for tomato varieties with fruit > 1 inch. Can be used on peppers and eggplant.
Requiem EC	2 to 4 qt	-	-
Rimon 0.83 EC	12 fl oz	36 fl oz	Allow 7 days between applications. For immature control only.
Scorpion 35 SL	2 to 7 fl oz	10.5 fl oz	Allow 7 days between applications.
Torac 1.29 EC	21 fl oz	42 fl oz	Limit 2 applications. Allow 14 days between applications.
Venom 70 SG	1 to 4 oz	6 oz	Allow 7 days between applications.
Whiteflies			
Admire Pro	1.3 to 2.2 fl oz	6.7 fl oz	Allow 5 days between applications. Not during bloom.
Courier 40 SC	9 to 13.6 fl oz	27.2 fl oz	Allow 5 days between applications. Limit 2 applications.
Exirel 0.83 SE	13.5 to 20.5 fl oz	61.5 fl oz	Allow 5 days between applications. Use a spray adjuvant.
Fulfill 50 DF	2.75 oz	5.5 oz	Allow 7 days between applications.
Knack 0.86 EC	8 to 10 fl oz	16 fl oz	Allow 14 days between applications. Limti 2 applications.
Oberon 2 SC	7 to 8.5 fl oz	25.5 fl oz	Limit 3 applications.
PQZ 1.87 SC	2.4 to 3.2 fl oz	4.8 fl oz	Limit 2 applications. Allow 7 days between applications.
Requiem EC	2 to 3 qt	-	-
Rimon 0.83 EC	12 fl oz	36 fl oz	Allow 7 days between applications. For immature control only.
Scorpion 35 SL	2 to 7 fl oz	10.5 fl oz	Allow 7 days between applications.
Venom 70 SG	1 to 4 oz	6 oz	Allow 7 days between applications.

1 See An IPM Scouting Guide for Common Problems of Solanaceous Crops in Kentucky (ID-172) for photos of pests.
2 Generic products available (Appendix G).

WEED CONTROL: Fruiting Vegetables - Egglplant, Pepper, and Tomato

Product Amt/A	Lb A.I./A	Comments
0.5 to 1.6 fl oz Aim 1.9 EW	0.008 to 0.025 carfentrazone	For contact post-emergence control of annual broadleaf weeds and suppression of annual grasses. Can be applied as a preplant, pre-transplant burndown, or before crop emerges to actively growing weeds up to 4 inches tall. Can also be applied post-emergence as a directed hooded application between crop rows. Use min. 10 gal of water/A and crop oil 1% v/v. Max. rate 6.1 fl oz/A. PHI = 0 days.
0.67 to 2.67 pt Command 3ME	0.25 to 1 clomazone	Pepper only - For pre-emergence control of annual grasses and broadleaves. Apply and incorporate 1 to 2 inches before transplanting. Use in combination with other herbicides like Treflan or Devrinol to broaden the weed control spectrum. Can be used on bell, hot, pimento, and sweet peppers but not on banana peppers. Be sure to set transplants with their roots below chemical barrier when transplanting.
6-14 lb Dacthal W-75	4.5 to 10.5 DCPA	Eggplant and tomato - For pre-emergence control of annual grasses and small-seed broadleaves. Over-the-top application 4 to 6 weeds after transplanting is safe to plants. Plants should be well established. Do not apply if growing conditions are poor (i.e.. cool, wet weather).
2 to 4 lb Devrinol DF-XT 2 to 4 qt Devrinol 2-XT	1 to 2 napropamide	For control of annual grasses and broadleaves. Apply to weed free soil before transplanting and water-in or incorporate to a depth of 1 to 2 inches. If grown on beds covered with plastic mulch, apply to the bed immediately in front of the laying of the plastic mulch. If soil is dry, water or sprinkler irrigate with sufficient water to wet to a depth of 2-4 inches before covering with plastic mulch. Apply the plastic mulch over the treated soil the same day. Can be applied on bare ground middles between beds of plastic 24 hours before rain or if watered-in or incorporated. To avoid injury, do not replant with crops not specified on the label until 12 months if using the 4-lb rate.
1.0 to 2.0 pt Dual Magnum	0.95 to 1.9 s-metolachlor	Tomato - For pre-emergent control of selected weed species. In transplanted tomatoes if applied preplant incorporated, transplant to a depth greater than incorporation and use the lower rate range to avoid injury. Do not plant when cool, wet or poor growing conditions exist. Reduce risk by applying seven or more days prior to transplant. PHI = 90 days.
0.5 to 1.0 pt Dual Magnum	0.48 to 0.97 s-metolachlor	Pepper - See the "Dual Magnum 24(c) Label" section on page 15
1 to 2 pt Goal 2XL	0.25 to 0.5 oxyfluorfen	For pre-emergence and post-emergence control of certain annual grasses and most broadleaves. For fallow bed preparation only. Best if used with glyphosate for control of winter annual broadleaf weeds. Min. 30 days between application and transplanting.
2.0 to 4.0 pt Gramoxone Inteon	0.69 to 1.38 paraquat salt	For non-selective contact kill of annual grasses and broadleaf weeds and top-kill of perennial weeds. Apply preplant, pre-emergence, or before transplanting in min. 10 gal water/A. Apply banded or broadcast. Use higher rate for heavy weed infestations. Use non-ionic surfactant 0.25% v/v. **Paraquat product labels require applicators to take an EPA-approved training every 3 years to mix, load, and apply paraquat.**
4 to 6.4 oz League	0.19 to 0.3 imazosulfuron	Tomato only - For control of certain annual broadleaf weeds and nutsedge. Rainfall or irrigation needed for activation. No more than 6.4 oz per year. No more than one application per year.
2 to 4 oz Matrix	0.031 to 0.062 rimsulfuron	Tomato only - For pre-emergent control of broadleaves and grasses. Apply pre-emergence or post-emergence to actively growing weeds. PHI=45 days.
0.5 to 1.5 pt Poast 1.5	0.09 to 0.26 sethoxydim	For control of actively growing grasses only. See label for specific crop restrictions. Use high rate on Johnson grass. PHI = 20 days. Max. rate of 1.5 pt/application and 4.5 pt/season.
5 to 6 qt Prefar 4 E	5 to 6 bensulide	For control of grasses and broadleaf weeds in peppers and eggplant. Apply preplant and incorporate to 1 to 2 inch depth. Apply pre-emergence only if it can be watered in within 36 hours. Max. rate of 6 qt/season.
1.5 to 2 pt Prowl H2O 3.8 E	0.7 to 1 pendimethalin	For pre-emergence control of broadleaves and grasses. Apply preplant and incorporate prior to transplanting pepper or as a post-directed application to established plants. PHI = 70 days.
16 to 22 fl oz Roundup WeatherMax 5.5L	0.69 to 0.94 glyphosate-salt	For non-selective post-emergence control of annual and perennial grasses and broadleaf weeds. Use only AMS 1 to 2% v/v. Adding a non-ionic surfactant can reduce weed control effectiveness. Min. 3 days before seeding and min. 30 days before planting any non-labeled crop.
0.5 to 1 oz Sandea 75 DF	0.023 to 0.047 halosulfuron	Eggplant and pepper - For control of annual broadleaf weeds and yellow nutsedge. Can be applied in row middles of direct-seeded or transplanted eggplants and peppers. Avoid contact with the crop or with plastic if plastic mulch is used. Max. 2 applications/crop and 2 oz/A per season.

(continued on next page)

WEED CONTROL: Fruiting Vegetables - Egglplant, Pepper, and Tomato *(continued)*

Product Amt/A	Lb A.I./A	Comments
0.5 to 1 oz Sandea 75 DF	0.023 to 0.047 halosulfuron	Tomato - For control of broadleaf weeds and yellow nutsedge. For transplanted tomato: may be applied preplant under the plastic. Apply after final bed shaping but before installation of plastic. Transplant 7 days after plastic installation. As a post-transplant application, Sandea can also be applied over the top or as a directed spray or with shields, 14 days after plastic installation. Max. 2 applications/crop and 2 oz/A per season. See label for row middle applications and direct-seeded tomato.
9 to 16 fl oz Select Max	0.07 to 0.12 clethodim	Eggplant and pepper - For selective post-emergence of actively growing annual grasses and suppression of perennial grasses. Add crop oil 1% v/v. Max. 16 fl oz/application. Min. 14 days between applications. PHI = 20 days.
9 to 32 fl oz Select Max	0.07 to 0.24 clethodim	Tomato - For selective post-emergence of actively growing annual grasses and suppression of perennial grasses. Add crop oil 1% v/v. Max. 16 fl oz/ application. Min. 14 days between applications. PHI = 20 days.
2.25 to 6 fl oz Spartan 4F	0.07 to 0.19Sulfentrazone	Transplanted tomato only. For selective pre-emergence control of control of susceptible broadleaves, grass and sedge weeds May be applied as a broadcast or banded treatment prior to transplant.
1.25 to 2 pt Treflan HFP 4 E	0.62 to 1 trifluralin	For pre-emergence control of annual grasses and broadleaf weeds. For transplanted pepper use only. Apply as preplant soil incorporated before transplanting.
0.3 to 1.3 lb TriCor DF	0.2 to 1 metribuzin	Tomato only. For control of annual grasses and broadleaves. Preplant: apply in min. 10 gal water/A immediately before transplanting and incorporate 2 to 4 inches. Best if used with Treflan to improve weed control. Transplant tomato with roots below herbicide zone. Post-emergence broadcast (0.3 to 0.6 lb/A) or post-emergence directed (0.6 to 1.3 lb/A): apply when plants have recovered from transplant shock and new growth is evident (about 2 weeks). Do not apply within 24 hours of other pesticides or within 3 days after cool, wet, or cloudy weather. Allow 14 days between applications. May be applied to plastic mulch row middles. PHI = 7 days.

DISEASE CONTROL: Tomatoes, Peppers, and Eggplant

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Anthracnose, Cercospora Leaf Spot, Early Blight, Leaf Mold, Gray Leaf Spot, Botrytis Gray Mold, Septoria Leaf Spot, Powdery Mildew					
Aftershock and fluoxastrobin[3] generics	11	3	2 to 5.7 fl oz	4 apps	Early blight and target spot.
Ariston	M/27	3	2 to 3 pt	17.5 pt	See label for specific rates per crop.
Aprovia Top	7/3	0	10.5 to 13.5 oz	53.6 oz	
Botran 75 W	14	10	1 lb	4 apps	Botrytis stem canker. Greenhouse only.
Cabrio and pyraclostrobin[3] generics	11	0	8 to 16 oz	96 oz	Not for gray leaf spot/mold. Use 8 to 16 oz/A for powdery mildew and Botrytis gray mold; apply 8 to 12 oz/A for other foliar diseases
Chlorothalonil[3]					Use higher rates fruit rots on tomato. There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Bravo Ultrex	M	0/3	1.3/2.6 lb	10/18 lb	
Bravo Weather Stik	M	0/14	1.5 to 2.75 pt	16/20 pt	
Copper, fixed coppers	M	0			Not for Botrytis, powdery mildew. See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Dexter Max	M/11	5	1.6 to 3.2 lb	12 lb	Tank mixing with a fixed copper product will also manage bacterial diseases.
Dexter XCEL	M/11/3	7	36 oz	1.7 gal	Do not use adjuvants or tank mix with an EC product.
Emblem	12	0	5.5 to 7 fl oz	28 oz	Gray mold, powdery mildew. Greenhouse only, not for field use.
Endura and boscalid generics	7	0	2.5 to 12.5 oz	6 apps	Early blight, Botrytis gray mold, and Sclerotinia white mold (timber rot). Use higher rates for gray and white mold.
Flint Extra	11	3	2 to 4 oz	5 apps	

(continued on next page)

DISEASE CONTROL: Tomatoes, Peppers, and Eggplant *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Fontelis	7	0	14 to 24 fl oz	72 fl oz	Anthracnose, Botrytis gray mold, early blight, and Septoria leaf spot.
Gem	11	3	3 to 3.8 fl oz	5 apps	Anthracnose, Septoria, and powdery mildew.
Indar 2F	3	7	6 to 12 fl oz	48 fl oz	Peppers only. Cercospora leaf spot and powdery mildew.
Inspire Super	3/9	0	16 to 20 fl oz	47 fl oz	
Luna Sensation	7/11	3	5 to 7.6 fl oz	5 app	See label for specific rates. Suppression of anthracnose, timber rot (white mold), and southern blight.
Luna Tranquility	7/9	1	11.2 fl oz	54.7 fl oz	
Mancozeb[3]					Not for Botrytis or powdery mildew. See label for rates. Addition of Latron surfactant will improve performance. There are multiple Dithane formulations and mancozeb generics on the market. See label for rates.
Dithane F-45	M	5/7	1.2 to 2.4 qt	14/16 qt	
Dithane M45	M	5/7	1.5 to 3 lb	18/21 lb	
ManKocide	M	5	2.5 to 5 lb	see footnote	Not for Botrytis or powdery mildew.
Mettle	3	0	6.0 to 8.0 fl oz	5 apps	
Miravis Prime	7/12	0	9.2 to 11.4 oz	22.8 oz	
Orondis Opti	49/M	7	1.75 to 2.5	10 pt	Do not combine with other Orondis products. Can be used in greenhouse on tomatoes only.
Priaxor	7/11	7	4 to 8 fl oz	24 fl oz	Anthracnose, Botrytis gray mold, early blight, and Septoria.
Quadris and azoxystrobin generics	11	0	5 to 15.5 fl oz	35/60 fl oz	Not for gray mold. Lower rates for tomatoes. Refer to label for tank mix and rate.
Quadris Opti	11/M	0	1.6 pt	5 apps	Not for gray mold, gray leaf spot, or leaf mold.
Quadris Top	11/3	0	8 fl oz	47 fl oz	
Quintec	13	3	4 to 6 fl oz	24 oz	Peppers only. Powdery mildew.
Rally 40 WSP and myclobutanil generics	3	0	2.5 to 4 oz	1.25 lb	Powdery mildew.
Reason	11	14	5.5 to 8.2 fl oz	24.3 fl oz	Early blight and Septoria.
Revus Top	40/3	1	5.5 to 7 fl oz	28 fl oz	Apply every 7 to 10 days. Use a spreader/penetrant surfactant.
Rhyme	3	0	3.5 to 7 fl oz	28 fl oz	Powdery mildew, Anthracnose, target spot, and early blight.
Scala	9	1	7 fl oz	35 fl oz	Early blight and Botrytis gray mold. Greenhouse use is approved.
Sulfur[3]	M				Powdery mildew. Phytotoxicity may occur if applications are made when temperatures exceed 90°F. See label for rates.
Switch 62.5 WG	9/12	0	11 to 14 oz	56 oz	Early blight, Botrytis, and powdery mildew.
Tanos	11/27	3	6 to 8 oz	5 apps	Not for Botrytis. Tanos must be tank-mixed with a fungicide from FRAC Group M appropriate for the target disease.
Toledo and tebuconazole[3] generics	3	7	8 fl oz	48 fl oz	Early blight and Septoria leaf spot. See label for rates.
Topguard EQ	3/11	0	4.0 to 8.0 fl oz	4 apps	Anthracnose, Cercospora, and powdery mildew.
Torac	39	1	21 oz	42 oz	Suppressive only on powdery mildew. Also an insecticide.
Torino	U6	0	3.4 oz	3 apps	Powdery mildew only.
Velum Prime	7	0	6.5 to 6.84 fl oz	13.7 fl oz	Powdery mildew, also soil-applied for nematode management (see label).

(continued on next page)

DISEASE CONTROL: Tomatoes, Peppers, and Eggplant *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Vivando	U8	0	15.4 fl oz	3 apps	Powdery mildew only.
Zing!	M/22	5	36 fl oz	8 apps	Early blight and Septoria.
Ziram 76DF Ziram XCEL	M	7	3 to 4 lb	24 lb	Anthracnose, early blight, and Septoria.
Bacterial Spot/Speck of Tomato and Pepper					
Actigard	21	14	0.33 to 0.75 oz	6 apps	Apply 1 week after transplanting or emergence; begin with lowest rate and increase as plants grow. May be applied through drip irrigation.
Copper, fixed coppers					Tank-mix with mancozeb for maximum efficacy (observe seasonal limits for EBDC fungicides). See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Mancozeb[3]					For bacterial spot/speck of tomato, use full rate of fixed copper in tank mix with half to full rate of Dithane. There are multiple Dithane formulations and mancozeb generics on the market. See label for rates.
Dithane F-45	M	5/7	1.2 to 2.4 qt	14/16 qt	
Dithane M45	M	5/7	1.5 to 3 lb	18/21 lb	
Streptomycin	25	n/a	16 oz/100 gal	n/a	Pre-transplant treatment. Apply when seedlings are in 2-leaf stage and continue every 4 to 5 days until transplanting. Alternate with fixed copper. Not for field use.
Tanos	11/27	3	8 oz	5 apps	Suppression only. Tanos must be tank-mixed with copper for best results against bacterial disease.
Late Blight					
Aftershock and fluoxastrobin[3] generics	11	3	5.7 fl oz	4 apps	Tank mix or alternate with a protectant fungicide at low rate.
Chlorothalonil[3]					Use higher rates fruit rots on tomato. There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Bravo Ultrex	M	0/3	1.3/2.6 lb		
Bravo Weather Stik	M	0/14	1.5 to 2.75 pt		
Copper,fixed coppers					See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Curzate 60 DF	27	3	3.2 to 5 oz	30 oz	Must be tank-mixed with a fungicide from FRAC Group M.
Forum SC	40	4	6 fl oz	30 fl oz	Must be tank-mixed with another *Phytophthora* fungicide.
Gavel 75 DF2	22/M	3	1.5 to 2 lb	8 apps	
Mancozeb[3]					There are multiple Dithane formulations and mancozeb generics on the market. See label for rates.
Dithane F-45	M	5/7	1.2 to 2.4 qt	14/16 qt	
Dithane M45	M	5/7	1.5 to 3 lb	18/21 lb	
ManKocide	M	5	1 to 3 lb	26.7 lb	For tomato only.
Micora	40		5.5 to 8.0 fl oz	2 apps	Transplant production only.
Orondis Gold 200	49/4	7	4.8 to 9.6 fl oz	19.2 fl oz	Phytophthora blight. Do not combine with applications of other Orondis products.
Orondis Opti	49/M	3	1.75 to 2.5 pt	10 pt	Do not combine with applications of other Orondis products.
Orondis Ultra	49/40	1	5.5 to 8 oz	4 app	Do not combine with applications of other Orondis products. Can be used in greenhouse on tomatoes only.
Presidio	43	2	3 to 4 fl oz	4 apps	Apply every 7 to 14 days. Must be tank-mixed with a fungicide NOT in FRAC Group 43.

(continued on next page)

DISEASE CONTROL: Tomatoes, Peppers, and Eggplant *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Previcur Flex	28	5	0.7 to 1.5 pt	7.5 pt	Must be tank-mixed with chlorothalonil or mancozeb.
Ranman SC	21	0	2.1 to 2.75 fl oz	6 apps	
Revus	40	1	5.5 to 8 fl oz	32 fl oz	Must be tank-mixed with a fungicide NOT in FRAC Group 40.
Revus Top	40/3	1	5.5 to 7 fl oz	28 fl oz	Use a spreader/penetrant surfactant.
Ridomil Gold Bravo SC	4/M	7	2.5 pt	3 apps	Also labeled for fungal diseases.
Ridomil Gold Copper	4/M				See label for specific rates per crop.
Ridomil Gold MZ2	4/M	5	2.5 lb	3 app	For tomato only.
Tanos	11/27	3	8 oz	5 apps	Tanos must be tank-mixed with a fungicide from FRAC Group M appropriate for the target disease.
Zampro	40/45	4	14 fl oz	3 apps	
Phytophthora Blight, Buckeye Rot in Pepper					
Badge X2, Badge SC	M	0	0.75 to 1.25 lb	42 lb	OMRI-listed. Also labeled for fungal diseases.
Elumin	22	2	8 oz	2 apps	
Forum SC	40	0	6 fl oz	5 apps	Must be tank-mixed with another *Phytophthora* fungicide.
Metastar 2E and metalaxyl generics	4	7			See label for specific rates and applications per crop.
Omega 500 and fluazinam generics	29	30	16 to 24 fl oz	6 apps	Soil drench or foliar application. Note extended PHI.
Orondis Gold 200	49	0	4.8 to 9.6 fl oz	19.2 fl oz	Use in tank mix with Ridomil Gold SL.
Orondis Ultra	49/40	1	5.5 to 8.0	4 app	Do not combine with applications of other Orondis products. Can be used in greenhouse on tomatoes only.
Presidio	43	2	3 to 4 fl oz	12 fl oz	Must be tank-mixed with a fungicide NOT in FRAC Group 43.
Ranman	21	0	2.75 fl oz	16.5 fl oz	Apply to base of plants at transplant or in transplant water, make additional applications within 7-10 days. Tank-mix with an organosilcone or non-ionic surfactant.
Reason 500 SC	11	14	8.2 fl oz	24.6 fl oz	Foliar and fruit phases of disease only.
Revus	40	1	8 fl oz	32 fl oz	Use a spreader/penetrant surfactant. Must be tank-mixed with a fungicide NOT in FRAC Group 40.
Ridomil Gold SL and mefenoxam generics	4	7	1 to 2 pt	3 pt	Suppression of Phytophthora blight. Broadcast, banded, or injection. See label for specific rates per crop.
Ridomil Gold Copper	4/M				See label for specific rates per crop.
Tanos	11/27	3	8 to 10 oz	72 oz	Foliar and fruit phase only. Tanos must be tank-mixed with a fungicide from FRAC Group M appropriate for the target disease.
Zampro	40/45	4	14 fl oz	3 apps	Apply at planting as a drench or by drip irrigation; make supplemental applications every 5 to 7 days.
Pythium Seedling Disease					
Metastar 2E and metalaxyl generics	4	7			See label for specific rates and applications per crop.
Previcur Flex	28	5	1.5 pt	7.5 pt	Field application. Can be directed at lower stems and soil, applied in transplant water, or delivered through drip irrigation. Greenhouse use. Can be applied as a drench or by chemigation—see to label for rates.

(continued on next page)

DISEASE CONTROL: Tomatoes, Peppers, and Eggplant *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Ridomil Gold SL and mefenoxam generics	4	7	1 to 2 pt	3 pt	Broadcast, banded, or injection. See label for specific rates per crop.
Ridomil Gold Copper	4/M				See label for specific rates per crop.
Ridomil Gold GR	4	7	20 lb	1 app	For preplant application only. Adjust equipment so that granules applied uniformly over soil surface. Incorporate mechanically or with irrigation water.
Southern Blight					
Aftershock and fluoxastrobin[3] generics	11	3	2 to 5.7 fl oz	4 apps	Tank mix or alternate with a protectant fungicide at low rate.
Cabrio and pyraclostrobin[3] generics	11	0	12 to 16 oz	96 oz	Suppression of Rhizoctonia, timber rot (white mold), and southern blight.
Luna Sensation	7/11	3	7.6 fl oz	5 app	Suppression of anthracnose, timber rot (white mold), and southern blight.
Rhizoctonia Stem and Root Rot					
Cabrio EG and pyraclostrobin[3] generics	11	0	12 to 16 oz	96 oz	Suppression of Rhizoctonia, Sclerotinia, and southern blight
Mural	11/7	0	0.6 to 0.8 oz/5,000 sq ft	2 apps	Rhizoctonia stem rot. Suppression of southern blight. For transplants produced for resale. See label for specific rates.
Orondis Opti	49/M	0	1.75 to 2.5 pt	4 app	Rhizoctonia fruit rot on tomato. See label for specific application detail.
Quadris and azoxystrobin generics	11	0	0.4 to 0.8 fl oz/ 1,000 row ft	3 app	Rhizoctonia seedling rot on pepper and eggplant. See label for specific application details.

1 Products with numerical FRAC codes must be alternated or tank-mixed with products that have a different FRAC code to discourage resistance development. See product label for maximum number of consecutive applications allowed. Refer to the table on pages 22-24 for more information on FRAC codes.
2 Pre-harvest interval.
3 Generic products available (Appendix F). Amounts and seasonal limits per acre are product dependent.

Greens

Collards, Kale, Lettuces, Mustards, Spinach, Swiss Chard, Turnip, and Others

Leafy greens or salad greens are consumed daily by most Americans, and nearly all types can be grown profitably in Kentucky. In fact, Kentucky was once known throughout the country for its "bibb" or "limestone" lettuce, named after Major John (Jack) Bibb, who, after fighting in the War of 1812, grew it in his garden in Frankfort. The large group of vegetable crops included under the broad term "greens" includes crops from several families: lettuces (romaine, leaf, bibb/Boston, iceberg, etc.); mustards (mustard greens, arugula, turnip greens); crucifers (collards, kale, broccoli raab, flowering or Chinese kale); spinach (flat leaf and savoy); composites (endive, escarole, radicchio, chicory, dandelion); and others including Swiss chard and beet greens. Various mixtures of green leafy vegetables ("mesclun") and immature "baby greens" are also very popular. Production guidelines for cole crops such as cabbage, broccoli, and some of the Asian vegetables are found in the chapter on "Cole Crops."

Most greens are cool-season crops that do best in the spring and fall, but heat-tolerant varieties for summer plantings are also available for some types. Many types of greens have also been successfully grown in Kentucky from September until June in unheated greenhouses or high tunnels (see Appendix K).

Production Systems

Production systems for this group are as varied as the crops themselves. Although greens have traditionally been grown as row crops at wide spacing in Kentucky, many growers are now planting at higher densities using raised beds with multiple rows per bed. Many of the crops in this group are most productive using raised beds with plastic mulch and drip irrigation. Greens are also grown on raised beds without plastic; however, weed control with hand/mechanical cultivation or with herbicides is critical when plastic mulch is not used. Black plastic mulch is used for spring plantings, and white mulch can be used for late summer plantings. Bed-shaping machines commonly used in Kentucky will form a 6-inch-high raised bed 30 to 32 inches wide at the top with 5 to 6 feet between centers of the beds. Depending on the crop and the between-row spacing, two to three rows can be used per bed. Growers in the Northeast make wider (4½ to 5½ feet), lower (4 to 5 inches high) beds on bare ground using a "meeker harrow" or roller and plant four to six rows of greens per bed, depending on the crop. This system relies heavily on the use of herbicides and overhead irrigation; similar systems are used in California but with drip irrigation.

Greens are either direct seeded and thinned or transplanted into either bare ground or plastic-mulched beds with drip irrigation. Pelleted seed is normally used for direct seeding, using a simple "Planet Jr."-type seeder or vacuum seeder. Transplanting will usually result in an earlier crop less exposed to insect damage, drought, or other early-season stresses. Some Kentucky growers have also produced leafy greens in tobacco "float beds" in the same way that tobacco transplants are grown. Keep in mind that few chemicals are available to manage diseases of greens grown in this manner. Going a step further, growers can produce high-quality bibb lettuce and other greens in traditional greenhouses using a hydroponic production system.

If transplants are used, crops are seeded in 128- to 288-cell plug trays in the greenhouse four to six weeks prior to going to the field. Harden the transplants by moving them outside the greenhouse for a few days prior to transplanting. Most greens are transplanted by hand or with a waterwheel setter onto raised beds with plastic mulch. One Kentucky grower has fabricated a three-row/bed waterwheel for this setter (8 inches within-row and 10 inches between rows) which has worked well for mustard and turnip greens. It should also be possible to use this wheel for leaf or bibb lettuce. See the table below for plant spacing used in the field for different types of greens.

Fertilizing and Cover Crops

A soil test should be taken in the fall or early spring prior to planting. Soil pH should be in the 6.0 to 6.8 range. Lime applications should be made in the fall if necessary.

Soil tests are critical to making appropriate recommendations for fertilizing vegetable crops and maintaining proper soil balance. Cover crops add organic matter and reduce weed pressure. Legume cover or green manure crops can also provide significant amounts of nitrogen. Winter cover crops include winter rye, wheat, ryegrass, or a mixture of winter rye and hairy vetch. Although this practice can delay planting, hairy vetch plowed under at 50 percent flowering in the spring (mid to late May) provides up to 80 pounds per acre of available nitrogen (140 to 160 pounds per acre total) to the following crop. Sudan grass or sorghum-Sudan grass hybrids ("Sudex") are used as summer cover crops on otherwise fallow land.

Apply all phosphorus and potassium according to soil test report recommendations prior to planting. Leafy vegetables require quick, continuous growth for best quality. Greens are high users of nitrogen, and most crops require a total of 100 to 150 pounds of nitrogen per acre. Apply 50 percent of the nitrogen together with phosphorus and potassium prior to planting. The remaining nitrogen is applied in two sidedressings on bare ground or is divided up and fertigated (injected) in equal weekly doses for plastic-mulched, drip-irrigated crops.

Tipburn and Bolting

Tipburn is a common and serious problem in lettuce and cole crops. Symptoms are brown leaf margins on the youngest leaves (sometimes concealed within the heads). It most often occurs during periods of drought followed by abundant moisture from rain or irrigation. In these cases the supply of calcium (which moves with the flow of water in plants) cannot keep up with the needs of rapidly growing new plant tissue. The calcium-deficient tissue collapses and turns brown, resulting in an unmarketable product.

Liming according to soil test results will help reduce the risk of tipburn as will any practice which ensures a regular moisture supply to plant roots. As is the case with blossom end rot, tipburn is more the result of lack of water or adverse weather conditions than a soil calcium deficiency. Excess application of ammonium nitrate can damage roots and cause tipburn as will deep cultivation, flooding, or drought. Plastic or organic mulches with drip irrigation also help reduce the risk of tipburn. Lastly, some varieties are less susceptible to the problem (see "Varieties" table).

Bolting is the formation of a flower stalk while the plant is still small or immature. Any stresses that slow vegetative growth can cause young plants to begin flowering. Generally for cool-season crops such as lettuce, favorable cool spring temperatures followed by periods of hot weather will lead to bolting. Lettuce should be harvested as soon as possible in spring crops to avoid excess heat and subsequent bolting. Seedlings subjected to low temperatures or water stress in the greenhouse prior to transplanting also are susceptible to bolting, as are transplants which are too old. Some growers have reported difficulty producing field-grown fall lettuce in Kentucky due to bolting. The practices discussed to reduce tipburn also will help reduce the risk of premature bolting. Variety selection is also important.

Harvesting and Handling

All fresh market leafy greens are hand harvested in Kentucky. Multiple harvests are possible from most types of greens. Baby greens are grown at closer spacings and are ready for market in a little more than half the time required to produce mature greens. Turnip, mustard, collards, and kale are harvested when stalks are fairly young and tender. Rubber bands can be used to bunch loose greens but larger wholesale buyers may require labels or bands with price-lookup (PLU) codes. Hydroponic producers routinely harvest lettuce with intact roots and market the product in clear clamshell containers. Harvesting hydroponic lettuce with roots intact can improve shelf-life. Turnip, mustard, collards, and kale are bunched with three to five stalks per bunch. Lower leaves that are discolored or dying are removed when bunching. Lettuces and spinach are often packed in cello bags. Greens can be field packed and top iced in waxed, corrugated cardboard boxes or wooden crates. Greens have high respiration rates and should be washed, packed, and sold as quickly as possible. Vacuum cooling to 34°F is the preferred method of pre-cooling, although forced air cooling is also possible. Greens are not usually stored for very long, although lettuce and other crops can be stored for two weeks at 32°F.

OPTIMUM IN-ROW AND BETWEEN-ROW SPACINGS: Greens

Most crops can be transplanted to 2 rows/bed using a waterwheel setter, using two wheels for 9- or 12-inch spacings.

Crop	In-row (in.)[1]	Between-row (in.)	No. rows/bed[2]
Collards	12-18	15-36	1-2
Kale	9-12	12-24	2
Mustard	9-15	12-15	2
Turnip			
for roots	3-4	12-18	2
for leaves	0.5-3	12-18	2
Brocolli raab	6-12	15-18	2
Lettuce			
leaf/bibb	9-12	12-18	2
romaine	9-12	12-18	2
Endive/escarole	12-18	15-18	2
Spinach	3-6	9-18	3-4
Swiss chard	6	18-24	2

1 Final spacing after thinning or transplanting.
2 Raised beds formed by Rainflo or similar bed shaper.

Variety	DTM[1]	Comments
COLLARDS[2]		
Top Bunch 2.0	70	Uniform hybrid that is 5 to 10 days earlier than Vates.
Flash	73	Vigorous uniform hybrid (Vates type); slow bolting.
Vates	75	Blue-green leaves; compact and uniform.
Champion	76	Slow bolting, good hardiness.
Georgia Southern	80	Blue-green leaves; produces under adverse temperatures.
KALE[2]		
Black Magic	45	Lacinato type; deep green color leaves with nearly white veins
Dazzling Blue	45	Lacinato type; dark pink mid-rib and veins with green leaves
Winterbor	50-55	Hybrid, finely curled dark green leaves; frost tolerant.
Darkibor	50-55	Hybrid, finely curled, blue-green leaves, slow bolting.
Red Russian	50	Purple stems, green, flat "oak-leaf" pattern leaves; used in salad mixes.
Redbor	55	Hybrid, finely curled, dark red and taller version of Winterbor.
Blue Curled Vates	57	Dark blue-green finely curled leaves; 15 to 20 inches tall.
White Russian	55-60	Flat dissected leaves with white stems, very tender, has done well in organic trials
MUSTARD[2]		
Savannah	35	Very early maturing, drought tolerant.
Tendergreen	40	Large, thick but tender leaves; cold resistant, mild flavor.
Southern Giant	45	Large plants, bright green leaves with crumpled frilled edges; for spring and fall.
Green Wave	45	Large plants, deeply frilled and finely cut leaves; heat tolerant and slow bolting.
Florida Broadleaf	50	Large plants, spreading oval, serrated dark green leaves.
TURNIPS/TURNIP GREENS[2]		
Alamo	33	Broad leaved greens, short petiole, slow bolting; for greens
All Top	35	Thick tender leaves, quick regrowth, slow bolting; for greens
Southern Green	40	Hybrid, very dark green, upright leaves, slow bolting.
BROCCOLI RAAB (RAPINI)[2]		
Spring Raab	42	Versatile variety for spring and summer harvests.
Zamboni	60	Large flower buds and uniform bud set, spring.
LETTUCE[3]		
Leaf/Looseleaf		
Grand Rapids	43	Early, old standard open-pollinated variety; light green leaves.
Red Sails	45-55	AAS winner; ruffled and fringed red leaves with green background; slow bolting and tipburn tolerant.
Tango	45	Pointed, deeply cut leaves (like endive), used in salad mixes.
Black-seeded Simpson	46	Early, old standard open-pollinated variety; light green leaves.
Salad Bowl	46	Oak-leaf type; light green, deeply lobed leaves; heat tolerant.
New Red Fire	48	Dark red, wavy, ruffled leaf margins; slow to bolt.
Simpson Elite	53	More ruffled and slower to bolt than Black-seeded Simpson.
Bibb/Butterhead/Boston		
Buttercrunch	44	Dark green, slow bolting, commonly grown
Harmony	50	Uniform butterhead type. Produces large heads with deep green color and smooth, glossy leaves. Intermediate resistance to bolting, tipburn, and Downy Mildew (races I, IIA, IIB, IV, V).
Pomegranate	50	Open, butterhead-like growth. Dark red leaves with light green on the inside. Resistance to Downy Mildew 1-8, 16-27, 29, 32.
Rex	50	For indoor hydroponic production, slow bolting, not for outdoor production
Nancy	52	Medium green leaves, large "heart;" mildew and virus resistant.
Sangria	55	Red butterhead type. Large round heads with smooth bright green leaves with red along the margins. Tender and flavorful. Resistant to bolting and tipburn.
Winter Density	55	Cross between butterhead and romaine. Leaves are deep green.
Milagro	55	Butterhead type. Leaves are bright green with tight head formation in the middle with looser leaves around the outside. Resistant to Downy Mildew (races 1-9, 16, 35), Fusarium Wilt (race 1), Tomato Bushy Stunt Virus, and Lettuce Mosaic Virus.
Romaine/Cos		
Coastal Star	65-70	Large heavy heads, sell as full head or heart, very heat tolerant

(continued on next page)

VARIETIES: Greens *(continued)*

Variety	DTM[1]	Comments
Parris Island	28 (58)	Commonly grown for baby romaine (28 days) or for mature heads (58), dark green, good flavor.
Green Forest	66	Dark green leaves, short core length
Green Towers	74	Dark green, lightly savoyed leaves.
ENDIVE/ESCAROLE[3]		
Natacha	48	Replaces 'Nataly'; very large heads; slow bolting, tipburn and bottom rot tolerant.
Lorca	90	Large, deep, blanched heads, tipburn resistant.
SPINACH[4]		
Flat Leaf		
Space	40	For trial, hybrid; smooth, dark green leaves; downy mildew resistant, slow to bolt.
Savoy		
Tyee	42	Hybrid; dark green, semi-savoy type; downy mildew resistant; heat tolerant and slower bolting than 'Spinner.'
Bloomsdale Long Standing	43	Open-pollinated; very hardy; savoyed dark green leaves; slow bolting.
Samish	45	For trial, hybrid, good cold hardiness, may be good for tunnels in winter.
Melody	45	Hybrid; deep green, semi-savoy type; downy mildew and mosaic tolerant, slow to bolt.
SWISS CHARD[4]		
Bright Lights	55	All America Selections winner; stalks of various colors.
Fordhook Giant	55	Very tall; dark green savoyed leaves with white stems/veins; heat tolerant.
Ruby Red (Rhubarb)	55	Deep green savoyed leaves with bright red rhubarb-like stems.
Silverado	60	Compact plants; dark green, deeply savoyed leaves with broad white stems.

1 From seeding. Days to maturity vary widely in seed catalog descriptions making comparisons difficult.
2 (Brassicaceae)—mustard family
3 (Asteraceae)—sunflower family
4 (Chenopodiaceae)—goosefoot family

FERTILIZER: Greens

Soil Test Results (lb/A)		Fertilizer Needed (lb/A)
Phosphorus		**Phosphate (P_2O_5)**
Low	<31	121-180
Medium	31-60	1-120
High	>60	0
Potassium		**Potash (K_2O)**
Low	<201	101-150
Medium	201-300	51-100
High	301-450	1-50
Very High	>450	0
Nitrogen		**N**

Apply 100 to 150 lb of actual nitrogen (N)/A. Apply 25 to 50% broadcast with other fertilizer before seeding or transplanting and disk in well. The remainder can be divided up into one or more sidedressings.

PESTICIDE SAFETY: Greens

	Signal[2]	Re-entry (hrs)	Harvest Interval (days)					
			Collards	Kale	Lettuce	Mustard	Spinach	Turnips
INSECTICIDES								
Actara 25 WP	C	12	7	7	7	7	7	-
Admire Pro	C	12	7/21[1]	7/21[1]	7/21[1]	7/21[1]	7/21[1]	7/21[1]
Assail 30 SG	C	12	3	3	3	3	7	3
Avaunt eVo 30 DG	C	12	3	3	3	3	3	3
Belay 2.13 SC	C	12	7/21[1]	7/21[1]	7/21[1]	7/21[1]	7/21[1]	-
Beleaf 50 SG	C	12	0	0	0	0	0	0
Bt products	C	12	0	0	0	0	0	0
Coragen 1.67 SC	-	4	3	3	1	3	1	-
Courier	W	12	1	1	1	1	1	1
Dimethoate 4 E	W	48	-	14	14	14	-	14
Exirel 0.83 SE	C	12	1	1	1	1	1	1
Fulfill 50 DF	C	12	7	7	7	7	7	7
Harvanta 50 SL	C	4	1	1	1	1	1	1
Intrepid 2 F	C	4	1	1	1	1	1	1
Knack 0.86 EC	C	12	7	7	14	7	14	7
Malathion 8	C	24	7	7	14	7	7	-
Movento 2 SC	C	24	1	1	3	1	3	-
Oberon 2 SC	C	12	-	-	7	7	7	-
Platinum 2 SC	C	12	30	30	30	30	30	-
PQZ 1.87 SC	C	12	1	1	1	1	1	1
Pyrethrin	C	12	0	0	0	0	0	0
Radiant SC	C	4	1	1	1	1	1	3
Requiem 25 EC	C	12	0	0	0	0	0	0
Scorpion 3.5 SL	C	12	-	-	7/21[1]	-	7/21[1]	-
Sevin XLR Plus	W	12	14	14	14	14	14	14
Sivanto 1.67 SL	C	12	1	1	1	1	1	1
Torac 1.29 EC	W	12	1	1	1	1	1	1
Trigard 75 WP	C	12	7	7	7	7	7	7
Venom 70 SG	C	12	1	1	7/21[1]	1	7/21[1]	1
Verimark 1.67 SC	-	4	AP	AP	AP	AP	AP	AP
Versys 0.83 SC	C	12	0	0	0	0	0	0
Restricted Use								
Agrimek 0.7 SC	W	12	-	-	7	-	7	-
Asana XL	W	12	7	-	-	7	-	-
Baythroid XL	W	12	-	-	0	0	0	0
Brigade 2 EC	W	12	7	7	7	7	40	7
Daizinon AG500	C	24	4	4	14	4	3	-
Diazinon 50 W	C	24	4	4	14	4	3	-
Dimilin 2L	C	12	7	7	-	7	-	7
Hero 1.24 EC	C	12	7	7	7	7	-	-
Lannate 90 SP	DP	48	10	10	10	10	7	10
Mustang Maxx	W	12	1	1	5	1	1	-
Permethrin 3.2 EC	C	12	1	-	1	-	1	1
Proaxis 0.5 EC	C	24	-	-	1	-	-	-
Proclaim 5 WDG	C	48	14	14	7	14	7	14
Warrior II	W	24	-	-	1	-	-	-

- Indicates crop does not appear on label.
1 PHI depends on the method of application.
2 W: Warning, C: Caution, D: Danger, P: Poison

PESTICIDE SAFETY: Greens

	Signal[3]	Re-entry (hrs)	Harvest (days)
FUNGICIDES			
Mustard, Turnips, Collards, Kale			
Actigard 50 WG	C	12	7
Azoxystrobin[2]	C	4	0
Cabrio EG	C	12	3
Cannonball	C	12	0
Endura	W	12	14
Fixed coppers[2]	D	12/24[1]	0
Flint Extra	C	12	0
Fluazinam	W	12	20
Fontelis	C	12	0
Forum SC	C	12	0
Inspire Super	C	12	7
Iprodione[2]	C	12/24	7/14
Luna Experience	C	12	7
Luna Sensation	C	12	0
Mefenoxam[2]	C	48	0
PCNB[2]	C	12	0
Presidio	C	12	2
Priaxor	C	12	3
Procure 480 SC	C	12	1
Propiconazole[2]	W	24	7
Quadris Top	C	12	1
Quilt	C	12	7
Ranman	C	12	0
Reason 500 SC	C	12	2
Revus	C	4	1
Rhyme	W	12	7
Sulfur[2]	C	12	0
Switch 62.6 WG	C	12	7
Tebuconazole[2]	C	12	7
Topguard EQ	C	12	7
Trionic	C	12	1
Velum Prime	C	12	0
Zampro	C	12	0
Lettuce			
Actigard 50 WG	C	12	7
Azoxystrobin[2]	C	4	0
Botran 75 W	C	12	14
Botran 5F	C	12	14
Cabrio EG	C	12	0
Cannonball WP	C	12	0
Curzate 60 DF	W	12	3
Endura	W	12	14
Fixed coppers[2]	D	24/48	1
Flint Extra	C	12	0/20
Fontelis	C	12	3
Forum SC	C	12	0
Iprodione[2]	C	24	14
Kenja	C	12	14
Luna Sensation	C	12	0

(continued)

PESTICIDE SAFETY: Greens *(continued)*

	Signal[3]	Re-entry (hrs)	Harvest (days)
Mancozeb[2]	C	24	10
Mefenoxam[2]	C	48	0
Metalaxyl[2]	W	48	0
Merivon	W	12	1
Miravis Prime	C	12	0
Orondis Gold 200	C	4	0
Orondis Ultra	C	4	1
Presidio	C	12	2
Previcur Flex	C	12	6
Quintec	C	12	1
Ranman	C	12	0
Reason 500 SC	C	12	2
Revus	C	4	1
Rhyme	W	12	7
Sulfur[2]	C	24	0
Switch 62.6 WG	C	12	0
Tanos	C	12	3
Topguard EQ	C	12	7
Torac	W	12	1
Zampro	C	12	0
Spinach			
Actigard 50 WG	C	12	7
Azoxystrobin[2]	C	4	0
Cabrio EG	C	12	0
Curzate 60 DF	W	12	3
Fixed coppers[2]	D	24/48[1]	0
Fontelis	C	12	3
Mefenoxam[2]	C	48	21
Merivon	W	12	1
Metalaxyl[2]	W	48	21
Miravis Prime	C	12	0
Orondis Gold 200	C	4	0
Orondis Ultra	C	4	1
Presidio	C	12	0
Ranman	C	12	0
Revus	C	4	1
Rhyme	W	12	7
Ridomil Gold Copper	D	48	21
Sulfur[2]	C	24	0
Tanos	C	12	1
Topguard EQ	C	12	7
Torac	W	12	1
Zampro	C	12	0

[1] Varies by formulation. Check labels carefully.
[2] Several formulations are marketed. See the general introduction for more details on fungicides.
[3] W: Warning, C: Caution, D: Danger, P: Poison

INSECT CONTROL: Greens[1]

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
PREPLANT INCORPORATED			
Cutworms, Wireworms: Eliminate weeds from field margins and plow fields at least 2 weeks before planting to destroy cutworm food sources and egg laying sites. Wireworms can be a potential problem where greens follow grass or grass-legume sod.			
Diazinon AG 500	4 to 8 pt	-	Incorporate immediately. Lower rate for lettuce (4 pt limit).
SOIL APPLICATION			
Aphids, Whiteflies: Do not use a foliar spray of Actara, Assail, Belay Provado or Venom following a soil application of Admire, Belay, Platinum, or Venom.			
Admire Pro	4.4 to 10.5 fl oz	10.5 fl oz	Systemic control. See label for various application methods.
Belay 2.13 SC	9 to 12 fl oz	12 fl oz	At planting only.
Platinum 2 SC	5 to 11 fl oz	11 fl oz	-
Venom 70 SG	5 to 7.5 oz	12 oz	Not for collards, kale, or mustard greens.
FOLIAR TREATMENTS			
Aphids: Excessive nitrogen application favors increased aphid reproduction. Use no more nitrogen than is necessary. Eliminate remnants of fall crops to reduce numbers of overwintering eggs.			
Actara 25 W	1.5 to 3 oz	11 oz	Allow 7 days between applications. Not during bloom.
Admire Pro	1.3 fl oz	6.5 fl oz	Allow 5 days between applications. Not during bloom.
Assail 30 SG	2 to 4 oz	20 oz	Limit 4 applications. Allow 7 days between applications.
Belay 2.13 SC	3 to 4 fl oz	12 fl oz	Allow 10 days between applications. Not during bloom.
Beleaf 50 SG	2 to 2.8 oz	8.4 oz	Allow 7 days between applications.
Dimethoate 4 E	8 fl oz	16 fl oz	Allow 3 to 15 days between treatments.
Exirel 0.83 SE	13.5 to 20.5 fl oz	61.5 fl oz	Allow 5 days between applications. Use an adjuvant.
Fulfill 50 DF	2.75 oz	5.5 oz	Allow 7 days between applications.
Lannate 90 SP	0.5 to 1 lb	4 lb	For spinach only.
		10 lb	For lettuce only.
Malathion 8	1 pt	2 applications	Allow 7 days between applications.
	1.88 pt	2 applications	Lettuce and spinach only. Allow 6 days between applications.
PQZ 1.87 SC	2.4 to 3.2 fl oz	4.8 fl oz	Allow 7 days between applications. Limit 2 applications.
Sivanto Prime 1.67 SL	7 to 14 fl oz	28 fl oz	Allow 7 days between applicatons.
Torac 1.29 EC	17 to 21 fl oz	42 fl oz	Limit 2 applications and allow 14 days between applications.
Venom 70 SG	1 to 3 oz	6 oz	Allow 7 days between applications.
Versys 0.83 SC	1.5 fl oz	14 fl oz	Allow 7 days between applications.
Flea Beetles			
Admire Pro	1.3 fl oz	6.5 fl oz	Allow 5 days between applications. Not during bloom.
Belay 2.13 SC	3 to 4 fl oz	12 fl oz	Allow 10 days between applications. Not during bloom.
Brigade 2 EC	2.1 to 6.4 fl oz	25.6 fl oz	Allow 7 days between applications.
		32 fl oz	For lettuce only. Allow 7 days between applications.
Harvanta 50 SL	16.4 fl oz	49.2 fl oz	Allow 5 days between applications. Three applicatons allowed.
Mustang Maxx	2.24 to 4 fl oz	24 fl oz	Allow 7 days between applications.
Proaxis 0.5 EC	2.56 to 3.84 fl oz	38.4 fl oz	-
Scorpion 35 SL	2 to 5.25 fl oz	10.5 fl oz	Allow 7 days between applications.
Sevin XLR Plus	0.5 to 1 qt	4 applications	Allow 7 days between applications. Apply within 30 days of planting.
Torac 1.29 EC	17 to 21 fl oz	42 fl oz	Limit 2 applications and allow 14 days between applications.
Venom 70 SG	1 to 3 oz	6 oz	Allow 7 days between applications.
Warrior II	1.28 to 1.92 fl oz	19.2 fl oz	-
Grasshoppers, Leafhoppers, Leafminers			
Admire Pro	1.3 fl oz	6.5 fl oz	Allow 5 days between applications. Not during bloom. Leafhoppers only.
Brigade 2 EC	2.1 to 6.4 fl oz	25.6 fl oz	Allow 7 days between applications.
		32 fl oz	For lettuce only. Allow 7 days between applications.
Dimethoate 4 E	8 fl oz	16 fl oz	Allow 3 to 15 days between treatments.
Harvanta 50 SL	10.9 to 16.4 fl oz	65.6 fl oz	Allow 5 days between applications. For leafminers only.
Mustang Maxx	2.24 to 4 fl oz	24 fl oz	Allow 7 days between applications.
Permethrin 3.2 EC	2 to 8 fl oz	24 fl oz	-
Proaxis 0.5 EC	2.56 to 3.84 fl oz	38.4 fl oz	-

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INSECT CONTROL: Greens[1] *(contiued)*

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Sevin XLR Plus	0.5 to 1 qt	4 applications	Leafhoppers only. Allow 7 days between applications. Apply within 30 days of planting.
Sivanto 1.67 SL	7 to 14 fl oz	28 fl oz	Allow 7 days between applications. Leafhoppers only.
Torac 1.29 EC	17 to 21 fl oz	42 fl oz	Limit 2 applications and allow 14 days between applications. For leafhoppers.
Trigard 75 WP	2.66 oz	6 applications	Allow 7 days between applications. Leafminers only.
Warrior II	1.28 to 1.92 fl oz	19.2 fl oz	-
Whiteflies			
Actara 25 W	3 to 5.5 oz	11 oz	Allow 7 days between applications.
Admire Pro	1.3 fl oz	6.5 fl oz	Allow 5 days between applications. Not during bloom.
Assail 30 SG	2.5 to 5.3 oz	20 oz	Limit 4 applications. Allow 7 days between applications. Field use only.
Belay 2.13 SC	3 to 4 fl oz	12 fl oz	Allow 10 days between applications.
Beleaf 50 SG	2.8 oz	8.4 oz	Allow 7 days between applications. Greenhouse whitefly only.
Courier 40 SC	9 to 13.6 fl oz	27.2 fl oz	Allow 7 days between applications. Limit 2 applications.
Exirel 0.83 SE	13.5 to 20.5 fl oz	61.5 fl oz	Allow 5 days between applications. Use an adjuvant.
Knack 0.86 EC	8 to 10 fl oz	20 fl oz	Allow 14 days between applications.
Oberon 2 SC	7 to 8.5 fl oz	25.5 fl oz	Allow 7 days between applications.
PQZ 1.87 SC	2.4 to 3.2 fl oz	4.8 fl oz	Allow 7 days between applications. Limit 2 applications.
Requiem EC	2 to 4 qt	-	-
Scorpion 35 SL	2 to 5.25 fl oz	10.5 fl oz	Allow 7 days between applications.
Sivanto 1.67 SL	10.5 to 14 fl oz	28 fl oz	Allow 7 days between applications.
Venom 70 SG	1 to 3 oz	6 oz	Allow 7 days between applications.
Versys 0.83 SC	5 to 7 fl oz	14 fl oz	Allow 7 days between applications.

1 Generic products available (Appendix G).

WEED CONTROL: Greens[1]

Product Amt/A	lb A.I./A	Comments
0.5 to 1.6 fl oz Aim 1.9 EW	0.008 to 0.025 carfentrazone	For contact post-emergence control of annual broadleaf weeds and suppression of annual grasses. Can be applied as a preplant, pre-transplant burndown, or before crop emerges to actively growing weeds up to 4 inches tall. Can also be applied post-emergence as a directed hooded application between crop rows. Use min. 10 gal water/A and crop oil 1% v/v. Max. rate 6.1 fl oz/A. PHI = 0 days.
6 to 14 lb Dacthal 75W	4.5 to 10.5 DCPA	For pre-emergence control of annual grasses and small-seeded broadleaves. Apply at seeding. Can be preplant incorporated.
1 to 2 pt Goal 2XL	0.25 to 0.5 oxyfluorfen	NOT LABELED ON COLLARDS, KALE, MUSTARD OR TURNIP GREENS. For pre-emergence and post-emergence control of certain annual grasses and most broadleaves. For fallow bed preparation only. Best if used with glyphosate for control of winter annual broadleaf weeds. Min. 90 days at 1 pt/A and 120 days at 2 pt/A between application and seeding.
2 to 4 pt Gramoxone Inteon	0.67 to 1.35 paraquat salt	ONLY LABELED FOR COLLARDS, CHINESE CABBAGE AND LETTUCE. For non-selective contact kill of annual grasses and broadleaf weeds and top-kill of perennial weeds. Apply preplant, pre-emergence, or before transplanting in min. 10 gal water/A. Apply banded or broadcast. Use higher rate for heavy weed infestations. Use non-ionic surfactant 0.25% v/v. **Paraquat product labels require applicators to take an EPA-approved training every 3 years to mix, load, and apply paraquat.**
2 to 4 lb Kerb 50 WP	1 to 2 pronamide	LABELED ON LETTUCE ONLY. For control of grasses and certain broadleaf weeds. Apply before or after seeding but before crop and weeds emerge. Moisture is necessary to activate. Label rates vary depending on variety, rainfall, and soil texture. Can be incorporated or watered in.
0.5 to 1.5 pt Poast	0.09 to 0.27 sethoxydim	For control of actively growing grasses only. Use high rate on Johnson grass. PHI = 30 days. Max. rate of 1.5 pt/application and 3 pt/season.
5 to 6 qt Prefar 4 E	5 to 6 bensulide	NOT LABELED ON SPINACH or TURNIP. For control of grasses and broadleaf weeds. Apply preplant and incorporate to 1 to 2 inch depth. Apply pre-emergence only if it can be watered in within 36 hours. Max. rate of 6 qt/season.
16 to 22 fl oz Roundup WeatherMax 5.5L	0.69 to 0.94 glyphosate-salt	For non-selective post-emergence control of annual and perennial grasses and broadleaf weeds. Use only AMS 1 to 2% v/v. Adding a non-ionic surfactant can reduce weed control effectiveness. Min. 3 days before seeding and min. 30 days before planting any non-labeled crop.

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WEED CONTROL: Greens[1] *(continued)*

Product Amt/A	lb A.I./A	Comments
9 to 16 fl oz Select Max	0.06 to 0.12 clethodim	For selective post-emergence of actively growing annual grasses and suppression of perennial grasses. Add crop oil 1% v/v. Max. 16 fl oz/ application. Min. 14 days between applications. PHI = 14 days for leafy greens but PHI = 30 days for leaf petioles (i.e. Swiss Chard)
1.5 pt Treflan HFP 4 E	0.75 trifluralin	NOT LABELED ON SPINACH AND LETTUCE. For control of annual grasses and broadleaf weeds. Use on turnip greens used for processing only. Apply as a preplant soil incorporated treatment.

1 Due to the wide range of crops grown under the title "Greens," growers must carefully read labels before applying herbicides.

DISEASE CONTROL: Greens

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
MUSTARD, TURNIP, COLLARDS, KALE					
Black Spot (*Alternaria*), Cercospora, Cercosporella Leaf Spots					
Cabrio and pyraclostrobin[3] generics	11	3	12 to 16 oz	64 oz	
Endura	7	14	6 to 9 oz	2 apps	Not for turnip greens.
Copper, fixed coppers[3]	M				See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Flint Extra	11	0	3.0 to 3.8 oz	7.6 oz	Black spot and powdery mildew. Apply preventatively and rotate with a non group 11 fungicide.
Fontelis	7	0	14 to 30 fl oz	72 fl oz	
Inspire Super	3/9	7	16 to 20 fl oz	80 fl oz	
Luna Experience	7/3	7	6.0 to 8.6 fl oz	34 fl oz	
Luna Sensation	7/11	0	4.0 to 7.6 fl oz	23 fl oz	
Priaxor	7/11	3	6 to 8.2 fl oz	3 apps	
Procure 480SC	3	1	6 to 8 fl oz[4]	18 fl oz	Black spot.
Quadris and azoxystrobin[3] generics	11	0	6 to 15.5 fl oz	42 fl oz	Use higher rates for Cercospora. May be applied through drip irrigation.
Quadris Top	11/3	1	12 to 14 fl oz	56 fl oz	
Rhyme	3	7	5 to 7 fl oz	4 apps	
Reason 500 SC	11	2	8.2 fl oz	24.6 fl oz	
Switch 62.5WG	9/12	7	11 to 14 oz	56 oz	
Toledo and tebuconazole[3] generics	3	7	3 to 4 fl oz	16 fl oz	Cercospora.
Tilt and propiconazole[3] generics	3	7	3 to 4 fl oz	12 fl oz	May be applied by drip irrigation.
Topguard EQ	3/11	7	5.0 to 8.0 fl oz	4 apps	
Trionic	3	1	6 to 8 fl oz	16 fl oz	Black spot and powdery mildew.
Black Rot					
Actigard	21	14	0.5 to 1 oz	4 apps	Not for turnip greens. Suppression only of black rot (*Xanthomonas)*. See label for application instructions. May be applied through drip irrigation. May cause phytotoxicity and yield reduction. Do not apply to stressed or injured plants.
Copper, fixed coppers[3]	M				See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Basal Stem Rot, Root Rot, Wirestem (*Rhizoctonia*), Clubroot (*Plasmodiophora*)					
Omega 500 and fluazinam[3] generics	29	20			Clubroot. Apply in transplant water or incorporate into soil. See label for rates and instructions.
Luna Experience	7/3	7	6.0 to 8.6 fl oz	34 fl oz	Suppression only for Rhizoctonia bottom rot.

(continued on next page)

DISEASE CONTROL: Greens *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Quadris and azoxystrobin[3] generics	11	0	0.4 to 0.8 fl oz per 1000 row ft	42 fl oz	Preplant or post plant application, banded or in furrow. See label for instructions. May be applied through drip irrigation.
Damping-off (*Pythium*)					
Presidio	43	2	3 to 4 fl oz	12 fl oz	Must be tank-mixed with a fungicide NOT in FRAC Group 43. Can be applied by drip-irrigation.
Ranman	21	0	2.75 fl oz	1 app	Prior to planting, apply as a banded spray followed by incorporation. Can be applied as a drench at planting or in transplant water; see label for instructions.
Ridomil Gold and mefenoxam[3] generics	4	7	1 to 2 pt	2 pt	Preplant or post plant application, broadcast or band. See label for instructions. Some products can be injected through drip irrigation.
Downy Mildew					
Actigard	21	14	0.5 to 1 oz	4 apps	Not for turnip greens. See label for application instructions. May be applied through drip irrigation. May cause phytotoxicity and yield reduction. Do not apply to stressed or injured plants.
Cabrio and pyraclostrobin[3] generics	11	3	12 to 16 oz	64 oz	
Copper, fixed coppers[3]	M				See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Forum SC	40	0	6 fl oz	30 fl oz	Must be tank-mixed with another downy mildew product NOT in FRAC Group 40.
Luna Sensation	7/11	0	4.0 to 7.6 fl oz	23 fl oz	Suppressive only.
Orondis Gold 200	49	0	4.8 to 9.6 fl oz	19.2 fl oz	Do not combine with foliar applications of Orondis Opti.
Presidio	43	2	3 to 4 fl oz	12 fl oz	Must be tank-mixed with a fungicide NOT in FRAC Group 43.
Ranman	21	0	2.75 fl oz	39.5 fl oz	Tank-mix with an organosilcone or non-ionic surfactant.
Reason 500 SC	11	2	5.5 to 8.2 fl oz	24.6 fl oz	
Revus, Micora, and mandipropamid generics	40	1	8 fl oz	32 fl oz	Revus, use a spreader/penetrant surfactant. Must be tank-mixed with a fungicide NOT in FRAC Group 40. Micora for transplant production only.
Topguard	3/11	7	6.0 to 8.0 fl oz	4 apps	Use high rate for downy mildew.
Zampro	40/45	0	14 fl oz	3 apps	
Powdery Mildew					
Cabrio and pyraclostrobin[3] generics	11	3	12 to 16 oz	64 oz	
Endura	7	14	6 to 9 oz	2 apps	Not for turnip greens.
Fontelis	7	0	14 to 30 fl oz	72 fl oz	
Inspire Super	3/9	7	16 to 20 fl oz	80 fl oz	
Luna Experience	7/3	7	6.0 to 8.6 fl oz	34 fl oz	
Luna Sensation	7/11	0	5.0 to 7.6 fl oz	23 fl oz	
Priaxor	7/11	3	6 to 8.2 fl oz	3 apps	
Procure 480SC	3	1	6 to 8 fl oz[4]	18 fl oz	
Quadris and azoxystrobin[3] generics	11	0	6 to 15.5 fl oz	42 fl oz	May be applied through drip irrigation.
Quadris Top	11/3	1	12 to 14 fl oz	56 fl oz	
Rhyme	3	7	5 to 7 fl oz	4 apps	
Sulfur[3]	M				Phytotoxicity may occur when sulfur is applied when temperatures exceed 90°F.
Switch 62.5WG	9/12	7	10 to 12 oz	56 oz	Rate is 11 to 14 oz for turnip greens.

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DISEASE CONTROL: Greens *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Toledo and tebuconazole[3] generics	3	7	3 to 4 fl oz	16 fl oz	
Tilt and propiconazole[3] generics	3	7	3 to 4 fl oz	12 fl oz	May be applied by drip irrigation.
Topguard EQ	3/11	7	6.0 to 8.0 fl oz	4 apps	Use high rate for downy mildew.
Trionic	3	1	6 to 8 fl oz	16 fl oz	Black spot and powdery mildew.
Velum Prime	7	0	6.5 to 6.84 fl oz	13.7 fl oz	Can be applied to foliage or through drip application.
Sclerotinia Stem Rot					
Cabrio and pyraclostrobin[3] generics	11	3	12 to 16 oz	4 apps	
Endura	7	14	6 to 9 oz	2 apps	Not for turnip greens.
Fontelis	7	0	16 to 30 fl oz	72 fl oz	
Luna Experience	7/3	7	6.0 to 8.6 fl oz	34 fl oz	
Luna Sensation	7/11	0	7.6 fl oz	23 fl oz	
LETTUCE					
Bottom Rot (*Rhizoctonia*)					
Cueva	M	0	0.5 to 2 gal		OMRI-listed. Mix in 100 gallons of water, use 50 to 100 gal/A of solution.
Endura	7	14	8 to 11 oz	2 apps	
Kenja	7	14	12.3 oz	24.6 oz	
Luna Sensation	7/11	0	7.6 fl oz	23 fl oz	Suppressive only.
Rovral and iprodione[3] generics	2	14	1.5 to 2 pt	3 app	Make first application from planting to just after thinning. See label for application instructions.
Quadris and azoxystrobin[3] generics	11	0	0.4 to 0.8 fl oz per 1000 row ft	42 fl oz	Preplant or post plant application, banded or in furrow. See label for instructions. May be applied through drip irrigation.
Damping-off (*Pythium*)					
MetaStar and metalaxyl[3] generics	4	21	4 to 8 pts	1 app	Preplant or post plant application, broadcast or band. See label for instructions.
Previcur Flex	28	6	2 pt	8 pt	Apply to lower stem and surrounding soil. See label for application instructions. May be applied by drip or sprinkler irrigation. Approved for greenhouse use.
Ranman	21	0	2.75 fl oz	1 app	Prior to planting, apply as a banded spray followed by incorporation. Can be applied as a drench at planting or in transplant water; see label for instructions.
Ridomil Gold and mefenoxam[3] generics	4	7	1 to 2 pt	2 pt	Preplant or post plant application, broadcast or band. See label for instructions. Some products can be injected through drip irrigation.
Downy Mildew					
Actigard	21	7	0.75 to 1 oz	4 apps	Apply after thinning and make up to three additional applications every 7 days. Apply in a min of 20 gal/A of water. May be applied through drip irrigation. May cause phytotoxicity—see label. Do not apply to stressed or injured plants.
Cabrio and pyraclostrobin[3] generics	11	0	16 oz	64 oz	
Curzate 60 DF	27	3	3.2 to 5 oz	30 oz	Head lettuce only. Must be tank-mixed with a protectant fungicide such as mancozeb.
Copper, fixed coppers[3]	M				See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Forum SC	40	0	6 fl oz	5 apps	Must be tank-mixed with another downy mildew product.
Dithane M45 and mancozeb[3] generics	M	10	2 lb	12 lb	There are multiple Dithane formulations and mancozeb generics on the market. See label for rates.

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DISEASE CONTROL: Greens *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
ManKocide	M	10	1 to 2 lb	26 lb	
Orondis Gold 200	49	0	4.8 to 9.6 fl oz	19.2 fl oz	Apply at crop establishment or through drip irrigation. Do not combine with foliar applications of Orondis.
Orondis Ultra	40/49	1	5.5 to 8.0 oz	32 oz	Apply at crop establishment or through drip irrigation. Do not combine with foliar applications of Orondis.
Presidio	43	2	3 to 4 fl oz	12 fl oz	Must be tank-mixed with a fungicide NOT in FRAC Group 43.
Previcur Flex	28	6	1.33 to 2 pt	8 pt	Apply to lower stem and surrounding soil. See label for application instructions. May be applied by drip or sprinkler irrigation. Approved for greenhouse use.
Quadris and azoxystrobin[3] generics	11	0	12 to 15.5 fl oz	90 fl oz	May be applied through drip irrigation.
Ranman	43	0	2.75 fl oz	16.5 fl oz	
Reason 500 SC	11	2	5.5 to 8.2 fl oz	24.6 fl oz	
Revus	40	1	8 fl oz	32 fl oz	Use a spreader/penetrant surfactant. Must be tank-mixed with a fungicide NOT in FRAC Group 40.
Tanos	11/27	3	8 oz	3 apps	Tanos must be tank-mixed with a fungicide from FRAC Group M appropriate for the target disease.
Topguard EQ	3/11	7	6.0 to 8.0 fl oz	4 apps	Use high rate for downy mildew.
Torac	39	1	21 oz	4 apps	Downy and powdery mildews, suppressive only.
Zampro	40/45	0	14 fl oz	3 apps	
Drop, Gray Mold					
Botran 75 W	14	14	2 to 5.33 lb	5.33 lb	Rates are timing dependent (pre-emergence, thinning, and post-thinning). See label for application instructions. Approved for greenhouse use.
Botran 5F	14	14	1.2 to 6.4 pt	6.4 pt	
Cannonball WP and fludioxonil[3] generics	12	0	7 oz	28 oz	May be applied through drip irrigation.
Endura	7	14	8 to 11 oz	2 apps	Apply immediately after emergence/ transplanting or before disease onset.
Flint Extra	11	0/20	3.0 to 3.8 oz	7.6 oz	Anthracnose, black spot, and powdery mildew.
Fontelis	7	3	16 to 24 fl oz	72 fl oz	
Rovral and iprodione[3] generics	2	14	1.5 to 2 pt	3 app	Drop. Make first application from planting to just after thinning. Repeat applications can be made every 10 days. See label for application instructions.
Kenja	7	14	12.3 fl oz	24.6 fl oz	Drop only. First application at crop establishment, follow with second app 14 days later.
Luna Sensation	7/11	0	7.6 fl oz	23 fl oz	
Merivon	7/11	1	4 to 11 fl oz	3 apps	
Miravis Prime	7/12	0	9.2 to 13.4 oz	2 apps	
Rhyme	3	7	5 to 7 fl oz	4 apps	
Switch 62.5WG	9/12	0	11 to 14 oz	56 oz	
SPINACH					
Damping-off (*Pythium*)					
MetaStar and metalaxyl[3] generics	4	21	4 to 8 pts	1 app	Preplant or post plant application, broadcast or band. See label for instructions.
Ranman	21	0	2.75 fl oz	1 app	Prior to planting, apply as a banded spray followed by incorporation. Can be applied as a drench at planting or in transplant water; see label for instructions.
Ridomil Gold and mefenoxam[3] generics	4	21	1 to 2 pts	2 pt	Preplant or post plant application, broadcast or band. See label for instructions.

(continued on next page)

DISEASE CONTROL: Greens *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Downy Mildew, White Rust					
Actigard	21	7	0.5 to 0.75 oz	3 apps	See label for application instructions. May be applied through drip irrigation. May cause phytotoxicity and yield reduction. Do not apply to stressed or injured plants.
Cabrio and pyraclostrobin[3] generics	11	0	16 oz	64 oz	Use highest rate for downy mildew.
Copper, fixed coppers[3]	M				See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Curzate	27	1/3	5.0 oz	30 oz	Use higher rate when environmental conditions are cool and damp.
MetaStar and metalaxyl[3] generics	4	21	4 to 8 pts	11 pt	Must be used at planting for white rust. Do not use as a foliar application. See label for application instructions.
Orondis Gold 200	49	0	4.8 to 9.6 fl oz	19.2 fl oz	Apply at crop establishment or through drip irrigation. Do not combine with foliar applications of Orondis.
Orondis Ultra	40/49	1	5.5 to 8.0 oz	32 oz	Apply at crop establishment or through drip irrigation. Do not combine with foliar applications of Orondis.
Presidio	43	0	3 to 4 fl oz	12 fl oz	Must be tank-mixed with a fungicide NOT in FRAC Group 43.
Quadris and azoxystrobin[3] generics	11	0	12 to 15.5 fl oz	90 fl oz	May be applied through drip irrigation.
Ranman	21	0	2.1 to 2.75 fl oz	13.75 fl oz	Tank-mix with an organosilicone or non-ionic surfactant.
Revus	40	1	8 fl oz	32 fl oz	Use a spreader/penetrant surfactant. Must be tank-mixed with a fungicide NOT in FRAC Group 40.
Ridomil Gold and mefenoxam[3] generics	4	21	0.25 pt	2 pt.	Not for foliar application. Post-plant sidedress application. See label for instructions.
Ridomil Gold Copper	4/M	21	2.5 lb	2 apps	Apply 21 days after initial (at-planting) treatment with Ridomil Gold EC or GR and continue every 14 days. Avoid late-season applications.
Tanos	11/27	1	8 to 10 oz	84 oz	Tank-mix with fixed copper.
Topguard EQ	3/11	7	6.0 to 8.0 fl oz	4 apps	Use high rate for downy mildew.
Torac	39	1	21 oz	4 apps	Downy and powdery mildews, suppressive only.
Zampro	40/45	0	14 fl oz	3 apps	Downy mildew.
Leaf Spots (Anthracnose, *Cercospora*)					
Cabrio and pyraclostrobin[3] generics	11	0	12 to 16 oz	4 apps	
Copper, fixed coppers[3]	M				See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Fontelis	7	3	16 to 24 fl oz	72 fl oz	
Merivon	7/11	1	4 to 11 fl oz	3 apps	Do not tank mix with other products for spinach.
Miravis Prime	7/12	0	9.2 to 13.4 oz	2 apps	
Quadris and azoxystrobin[3] generics	11	0			
Rhyme	3	7	5 to 7 fl oz	4 apps	
Topguard EQ	3/11	7	6.0 to 8.0 fl oz	4 apps	

1 Products with numerical FRAC codes must be alternated or tank-mixed with products that have a different FRAC code to discourage resistance development. See product label for maximum number of consecutive applications allowed. Refer to the table on pages 22-24 for more information on FRAC codes.
2 Pre-harvest interval.
3 Generic products available (Appendix F). Amounts and seasonal limits per acre are product dependent.
4 Use higher rate when pressure is severe.

Okra

Mallow family (Malvaceae): *Abelmoschus esculentus*

Planting and Culture

Well-drained, fertile, silt loam soils are most desirable; however, okra will grow on a wide range of soil types. Prepare a firm, friable seedbed as for other vegetable crops.

Seed okra only after the soil has warmed up (65°F) in the spring to allow good seed germination (see Appendix K). Plant four to six seeds per foot in rows 28 to 36 inches apart; thin plants to 10 to 18 inches apart in rows. Ten to 12 pounds of seed is required to plant an acre. Seed should be planted 1½ to 2 inches deep. Planet Jr.-type planters work well for direct seeding. In addition, very high yields have been obtained with transplanted okra using black plastic mulch and drip irrigation.

Fertilizing

Apply P_2O_5, K_2O, and lime according to soil test results. A total of about 80 to 90 pounds N per acre is used, with about half that amount applied prior to planting. Fertilizer should be applied broadcast and disked in prior to seeding. A sidedressing of nitrogen applied after the first harvest will help to prolong the harvesting period (see "Fertilizer" table). Soil pH should be 6.0 to 6.5.

Harvesting and Handling

Harvesting under favorable conditions should start about six days after flowering. Harvesting of the pods should be done on a regular basis (about every two days) so that the pods do not become over-mature. Regular picking increases yield. Old pods should be removed and discarded, because mature ones retard future pod set. The pods should be harvested when 2 to 3½ inches long. Move harvested pods to a shady, cool area as soon as possible to maintain good quality. Fresh market okra is usually graded into the following sizes:

- Fancy: pods up to 3½ inches long
- Choice: pods 3½ to 4½ inches long
- Jumbo: pods over 4½ inches long but still tender

Pods should be harvested from the plant with a sharp knife to make a smooth, neat cut.

Okra can be kept for fresh consumption for two weeks at a temperature of 50°F and a relative humidity of 90 to 95 percent. Okra chilled below temperatures of 50°F will turn dark and decay.

Potential yields of 12,000 pounds per acre are possible; however, 8,000 to 10,000 pounds per acre is considered more realistic. A bushel of okra weighs approximately 30 pounds.

VARIETIES: Okra

Variety	DTM[1] From Seeding	Comments
Jambalaya	50	Compact plant, uniform pods.
Burgundy	60	Dark Red Pods, flowers are edible and may be stuffed.
Clemson Spineless	55	Heavy yields—almost spineless pods.

1 Days to Maturity

FERTILIZER: Okra

Soil Test Results (lb/A)		Fertilizer Needed (lb/A)
Phosphorus		**Phosphate (P_2O_5)**
Low	<31	181-240
Medium	31-60	91-180
High	61-80	1-90
Very High	>80	0
Potassium		**Potash (K_2O)**
Low	<201	151-200
Medium	201-300	101-150
High	301-450	1-100
Very High	>450	0
Nitrogen		**N**

Apply 40 to 50 lb nitrogen (N)/A before planting seed. After harvest begins sidedress plants with an additional 35 to 40 lb N/A.

PESTICIDE SAFETY: Okra

	Signal[1]	Re-entry (hrs)	Harvest (days)
INSECTICIDES			
Acramite 50 WS	C	12	3
Admire Pro	C	12	21
Assail 30 SG	C	12	7
Avaunt eVo 30 DG	C	12	3
Beleaf 50 SG	C	12	0
Bt products	C	12	0
Coragen 1.67 SC	-	4	1
Exirel 0.83 SE	C	4	1
Harvanta 50 SL	C	4	1
Intrepid 2 F	C	4	1
Kanemite 15 SC	C	12	1
Knack 0.86 EC	C	12	1
Magister SC	W	12	3
Malathion 8	C	12	1
Miteus 0.42 EC	W	12	1
Movento 2 SC	C	24	1
Portal 0.4 EC	W	12	1
PQZ 1.87 SC	C	12	1
Radiant SC	C	4	1
Requiem 25 EC	C	4	0
Rimon 0.83 EC	W	12	1
Sefina 0.42 SC	C	12	0
Sevin XLR Plus	C	12	3
Sivanto Prime 1.67 SL	C	4	1
Torac 1.29 EC	W	12	1
Transform 50 WG	D	24	1
Verimark 1.67 Sc	-	4	1
Zeal 72 WP	C	12	7
Restricted Use			
Brigade 2 EC	W	12	7
Danitol 2.4 EC	W	24	3
Fastac 0.83 EC	D	12	1
Mustang Maxx	W	12	1
Proclaim 5 SG	C	12	7

(continued)

PESTICIDE SAFETY: Okra *(continued)*

	Signal[1]	Re-entry (hrs)	Harvest (days)
FUNGICIDES			
Aprovia Top	W	12	0
Ariston	C	12	3
Azoxystrobin[2]	C	12	0
Chlorothalonil[2]	C	12	3
Elumin	C	12	2
Emblem	C	12	0
Fixed coppers[2]	W	24/48	0
Fontelis	C	12	0
Inspire Super	C	12	0
Lektivar	W	12	30
Luna Experience	C	12	3
Luna Sensation	C	12	3
Mettle	C	12	0
Micora	C	4	
Miravis Prime	C	12	0
Orondis Gold	C	4	0
Orondis Ultra	C	4	1
Pageant Intrinsic	C	12	0
Quadris Top	C	12	0
Rally 40 WSP	W	24	0
Ranman	C	12	0
Reason	C	12	14
Rhyme	W	12	0
Sulfur[2]	C	24	0
Switch	C	12	0
Tebuconazole[2]	C	12	3
Topguard	C	12	0
Torac	W	12	1
Torino	C	4	0
Velum Prime	C	12	0
Vivando	C	12	0

1 W: Warning, C: Caution, D: Danger; P: Poison
2 Several formulations are marketed. See the general introduction for more details on fungicides.

INSECT CONTROL: Okra[1]

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Aphids			
Admire Pro	7 to 14 fl oz	14 fl oz	Soil application, see label for methods.
	1.3 to 2.2 fl oz	6.7 fl oz	Foliar application. Allow 5 days between applications. Not during bloom.
Assail 30 SG	2 to 4 oz	16 oz	Limit 4 applications. Allow 7 days between applications.
Beleaf 50 SG	2.8 to 4.28 oz	8.4 oz	Allow 7 days between applications. Limit 2 to 3 applications.
Malathion 8	1.2 pt	5 applications	Allow 7 days between applications.
Movento 2 SC	4 to 5 fl oz	10 fl oz	Allow 7 days between applications. Requires surfactant.
PQZ 1.87 SC	2.4 to 3.2 fl oz	4.8 fl oz	Limit 4 applications. Allow 7 days between applications.
Sefina 0.42 SC	3 fl oz	28 fl oz	Allow 7 days between applications.
Sivanto Prime 1.67 SL	7 to 14 fl oz	28 fl oz	Allow 7 days between applications.
Torac 1.29 EC	17 to 21 fl oz	42 fl oz	Allow 7 days between applications. Limit 2 applications.
Transform 50 WG	0.75 to 1 oz	8.5 oz	Limit 4 applications. Allow 7 days between applications.

(continued on next page)

INSECT CONTROL: Okra[1] *(continued)*

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Corn Earworms			
Avaunt eVo 30 WG	3.5 to 6 oz	14 oz	Allow 5 days between applications.
Brigade 2 E	2.1 to 6.4 fl oz	12.8 fl oz	Allow 7 days between applications.
Bt products	See labels		
Coragen 1.67 SC	3.5 to 7.5 fl oz	15.4 fl oz	Allow 5 days between applications.
Danitol 2.4 EC	10.67 fl oz	42.67 fl oz	Allow 7 days between applications.
Exirel 0.83 SE	7 to 13.5 fl oz	61.5 fl oz	Allow 5 days between applications.
Fastac 0.83 EC	2.2 to 3.8 fl oz	11.4 fl oz	Allow 7 days between applications.
Harvanta 50 SL	10.9 to 16.4 fl oz	49.2 fl oz	Allow 7 days between applications.
Intrepid 2 F	10 to 16 fl oz	64 fl oz	-
Mustang Maxx	2.24 to 4 fl oz	24 fl oz	Allow 7 days between applications.
Proclaim 5 SG	2.4 to 4.8 oz	14.4 oz	Allow 7 days between applications.
Radiant SC	5 to 10 fl oz	34 fl oz	Allow 4 days between applications.
Sevin XLR Plus	1 to 1.5 qt	6 qt	Allow 6 days between applications.
Japanese Beetles			
Brigade 2 E	2.1 to 6.4 fl oz	12.8 fl oz	Allow 7 days between applications.
Malathion 8	1.5 pt	5 applications	Allow 7 days between applications.
Stink bugs			
Brigade 2 EC	2.1 to 6.4 fl oz	12.8 fl oz	Allow 7 days between applications.
Danitol 2.4 EC	10.67 fl oz	42.67 fl oz	Allow 7 days between applications.
Fastac 0.83 EC	2.2 to 3.8 fl oz	11.4 fl oz	Allow 7 days between applications.
Mustang Maxx	3.2 to 4 fl oz	24 fl oz	Allow 7 days between applications.
Rimon 0.83 EC	12 fl oz	36 fl oz	For immatures only. Allow 7 days between applications.

1 Generic products available (Appendix G).

WEED CONTROL: Okra

Product Amt/A	lb A.I./A	Comments
0.5 to 1.6 fl oz Aim 1.9 EW	0.008 to 0.025 carfentrazone	For contact post-emergence control of annual broadleaf weeds and suppression of annual grasses. Can be applied as a preplant, pre-transplant burndown, or before crop emerges to actively growing weeds up to 4 inches tall. Can also be applied post-emergence as a directed hooded application between crop rows. Use min. 10 gal water/A and crop oil 1% v/v. Max. rate 6.1 fl oz/A. PHI = 0 days.
1.5 to 3.0 pt Caparol 4L	0.375 to 0.75 prometryn	Apply as pre-emergence or post-directed application. See label for crop rotation restrictions.
1 to 2 pt Dual Magnum	0.95 to 1.9 s-metolachlor	See the "Dual Magnum 24(c) Label" section on page 15.
2 to 4 pt Gramoxone Inteon	0.67 to 1.35 paraquat salt	For non-selective contact kill of annual grasses and broadleaf weeds and top-kill of perennial weeds. Apply preplant, pre-emergence, or before transplanting in min. 20 gal of water/A. Apply banded or broadcast. Use higher rate for heavy weed infestations. Use non-ionic surfactant 0.25% v/v. PHI = 21 days. **Paraquat product labels require applicators to take an EPA-approved training every 3 years to mix, load, and apply paraquat.**
1.5 pt Poast 1.5 E	0.28 sethoxydim	For control of actively growing grasses only. Use high rate on Johnson grass. PHI = 14 days. Max. rate of 1.5 pt/application and 5.5 pt/season.
16 to 22 fl oz Roundup WeatherMax 5.5L	0.69 to 0.94 glyphosate-salt	For non-selective post-emergence control of annual and perennial grasses and broadleaf weeds. Use only AMS 1 to 2% v/v. Adding a non-ionic surfactant can reduce weed control effectiveness. Min. 30 days before planting any non-labeled crop.
0.5 to 1.0 oz Sandea 75 DG	0.024 to 0.048	Apply to row middles as a postemergence shielded or hooded spray to avoid contact with planted crop. In plasticulture, do not allow spray to contact plastic. Do not apply more than 2 oz per acre per 12 month period. PHI = 30 days.
1.25 to 2 pt Treflan HFP 4 E	0.62 to 1 trifluralin	For pre-emergence control of annual grasses and broadleaf weeds. Apply as preplant soil incorporated. Can also be applied before or immediately after planting.

DISEASE CONTROL: Okra

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Foliar Diseases (Anthracnose, Leaf Spots, Powdery Mildew)					
Ariston	M/27	3	2.0 - 2.4 pt	17.5 pt	Anthracnose only.
Aprovia Top	3/7	0	10.5 to 13.5 oz	53.6 oz	Fungal leaf spots; also suppressive for southern blight.
Quadris and azoxystrobin[3] generics	11	0	6 to 15.5 fl oz[3]	4 apps	
Chlorothalonil[3]					There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Bravo Ultrex	M	14	1.4 lb	10.9 lb	
Bravo Weather Stik	M	3	1.5 lb	12 pt	
Emblem	12	0	5.5 to 7 fl oz[5]	28 fl oz	Gray mold, powdery mildew.
Copper, fixed coppers[3]	M	0			See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Fontelis	7	0	16 to 24 fl oz	72 fl oz	
Inspire Super	3/9	0	16 to 20 fl oz	47 fl oz	
Luna Experience	7/3	3	12.8 fl oz	34 fl oz	Cercospora leaf spot.
Luna Sensation	7/11	3	5.0 to 7.6 oz	27.1 oz	Fungal leaf spots.
Mettle	3	0	6.0 to 8.0 fl oz	5 apps	
Miravis Prime	7/12	0	9.2 to 11.4 oz	22.8 oz	Fungal leaf spots.
Pageant Intrinsic	7/11	0	9.7 to 23 oz	54 oz	Fungal leaf spots.
Quadris Top	11/3	0	8.0 to 14.0 oz	55.3 oz	Fungal leaf spots.
Rally and myclobutanil[3] generics	3	0	2.5 to 5 oz	4 apps	Powdery mildew.
Rhyme	3	0	7 fl oz	28 fl oz	Anthracnose, Cercospora leaf spot, powdery mildew.
Sulfur[3]	M	0	3 to 10 lb	n/a	Phytotoxicity may occur when sulfur is applied when temperatures exceed 90°F.
Switch 62.5 WG	9/12	0	11 to 14 oz	56 oz	Gray mold and powdery mildew.
Toledo and tebuconazole[3] generics	3	3	4 to 6 fl oz	24 fl oz	Cercospora leaf spot.
Topguard	3	0	14 fl oz	56 fl oz	Anthracnose, Cercospora leaf spot, powdery mildew.
Torac	39	1	21 oz	2 apps	Powdery mildew suppression only.
Torino	U6	0	3.4 oz	3 apps	Powdery mildew.
Velum Prime	7	0	6.5 to 6.84 oz	13.7 oz	Powdery mildew; also nematode suppression. Drip applications are effective for both.
Vivando	U8	0	15.4 fl oz	3 apps	Powdery mildew suppression only.
Phytophthora blight, crown and root rot					
Elumin	22	2	8 oz	16 oz	Phytophthora blight and root rot. Can be injected, applied to soil, or as a foliar spray.
Omega 500 and fluazinam[3] generics	29	30	16 to 24 oz	144 oz	Soil drench at transplanting followed by foliar applications. See label for application instructions.
Orondis Gold 200	49	7	4.8 to 9.6 fl oz	19.2 fl oz	Phytophthora blight. Do not combine with applications of Orondis Ultra.
Orondis Ultra	49/40	1	5.5 to 8.0 oz	32.0 fl oz	Phytophthora blight. Do not combine with applications of Orondis Gold.
Ranman SC	21	0	2.1 to 2.75 fl oz	6 apps	Phytophthora blight.
Reason 500 SC	11	14	5.5 to 8.2 fl oz	24.6 fl oz	Foliar application only.
Seedling Rot (*Rhizoctonia*)					
Quadris and azoxystrobin[3] generics	11	0	0.40 to 0.80 fl oz/1,000 ft	1 app	May be applied in-furrow or as banded spray. See label for additional details.

1 Products with numerical FRAC codes must be alternated or tank-mixed with products that have a different FRAC code to discourage resistance development. See product label for maximum number of consecutive applications allowed. Refer to the table on pages 22-24 for more information on FRAC codes.

2 Pre-harvest interval.

3 Generic products available (Appendix F). Amounts and seasonal limits per acre are product dependent.

Onions

Onion family (Alliaceae): *Allium cepa* Cepa group

Planting and Culture

Due to weed pressure, it is recommended that onion producers use transplants or sets for planting. The easiest way to grow green bunching onions is by using sets. Sets should be planted by mid-March for best results (see Appendix K).

Typically, transplants can be planted into the field about 8 to 10 weeks after seeding. At this time the base of the plants should be ¼ to ½ inch in diameter. Transplants can be planted into raised beds on rows 8 to 12 inches apart with in-row spacing between 6 and 8 inches. Some growers have had success using black or white plastic; however, growing onions on plastic can also increase the incidence of bacterial diseases in bulbs, particularly in hot or wet weather. If using plastic mulches, white-colored mulch is preferred for onion production due to the lower soil temperatures that occur. Use drip irrigation, as onions have poor root systems and will not achieve maximum size without adequate moisture. A well-drained soil is essential for good onion production. A soil pH between 6.0 and 6.8 is most desirable for onions.

Many growers produce onions for direct market sales. Often consumers at these markets are looking for sweet "Vidalia"-type onions. In order to produce mild tasting onions for fresh consumption, growers must have the correct combination of both variety and environment. Sweet, mild varieties bred specifically for fresh consumption should be chosen. In addition, onions grown with low levels of sulfur in soils or irrigation water will tend to be milder than those grown in a high sulfur environment. Growers should also be careful to choose the correct varieties for Kentucky. Intermediate or "day-neutral" type varieties perform well at this latitude.

Harvesting, Curing, and Storing

Onions should be harvested when at least 70 percent of the bulbs in the field have gone "tops-down" (foliage has fallen). Irrigation can be stopped about one week prior to harvest. At harvest, bulbs should be undercut and pulled by hand, with foliage and roots removed, and put in shallow trays inside for drying. Onions can be cured outside on a dry surface for one week prior to storing as long as they are protected from rain. Throw out diseased or injured bulbs. A temperature of 35°F and a relative humidity of 70 to 75 percent is the most desirable for storing onions for long periods. Do not store bulbs at a high relative humidity, as is appropriate for many other vegetables. Good ventilation is essential.

Green-bunching onions should be pulled and put into bunches (containing five to seven plants) when they are ⅓ to 1 inch in diameter. To achieve the long white shoulders desired on green onions, the soil is hilled around plants two to three weeks before harvest.

VARIETIES: Onions—Green and Bulb

Variety	DTM[1]	Comments
GREEN (BUNCHING/SCALLIONS)		
Ishikura Improved	60-66	Long very slim white stems
Evergreen White	65-70	Hardy, will overwinter, white stems
BULB		
Gunnison	100 (300)[1]	Medium bulbs, some success overwintering, for storage, hot and pungent.
Super Star	100	Large (3/4 lb) bulbs; white, pungent, stores well; AAS winner.
Candy	110	Large bulbs, sweet mild flavor, does very well in KY, not for storage.
Expression	110	Large bulbs, sweet mild, similar to Candy
Redwing	110-115	Red, medium bulbs, uniform, long day type will mature later.
Walla Walla	125 (300)[1]	Very large, sweet and mild, some success overwintering, stores poorly.
Yellow Sweet Spanish	130	Yellow, very large, globe-shaped, long-day onion will mature mid-late summer.

1 Days to maturity if overwintering.

FERTILIZER: Onions

Soil Test Results (lb/A)		Fertilizer Needed (lb/A)
Phosphorus		**Phosphate (P_2O_5)**
Low	<31	181-240
Medium	31-60	61-180
High	61-80	1-60
Very High	>81	0
Potassium		**Potash (K_2O)**
Low	<201	176-250
Medium	201-300	101-175
High	301-450	1-100
Very High	>450	0
Nitrogen		**N**

Apply 90 to 100 lb of nitrogen (N)/A to soils of relatively low fertility; broadcast and disk before planting. Decrease nitrogen application according to soil fertility. On heavily fertilized soils, apply 50 to 60 lb N/A. Once bulbing starts sidedress with 25 lb N/A every two weeks for a total of four applications.

PESTICIDE SAFETY: Onions

	Signal[1]	Re-entry (hrs)	Harvest (days)
INSECTICIDES			
Admire Pro	C	12	21
Assail 30 SG	C	12	4
Coragen 1.67 SC	C	4	1
Exirel 0.83SE	C	12	1
Intrepid 2 F	C	4	1
Knack 0.83 EC	C	12	3
Malathion 8	C	12	3
Movento 2 SC	C	24	3
Radiant SC	C	4	1
Requiem 25 EC	C	4	0
Scorpion 3.5 SL	C	12	AP/1
Torac 1.29 EC	W	12	7
Transform 50 WG	D	24	7
Venom 70 SG	C	12	1
Vantacor 5 SC	-	4	1
Verimark 1.67 SC	-	4	1
Restricted Use			
Agri-Mek 0.7 SC	W	12	30
Diazinon AG 500	C	24	14
Diazinon 50 W	C	24	14
Lannate 90 SP	DP	48	7
Mustang Maxx	W	12	7
Permethrin 3.2 EC	C	12	1
Proaxis 0.5 EC	C	24	14
Warrior II	W	24	14
FUNGICIDES			
Actigard 50WG	C	12	7
Ariston	C	12	7
Aprovia Top	W	12	7
Azoxystrobin[3]	C	12	0
Azoxystrobin + Propiconazole[3]	W	12	0
Azoxystrobin + Tebuconazole[3]	W	12	7
Botran	C	12	14
Cabrio EG	C	12	7
Cannonball	C	12	7
Chlorothalonil[3]	D	12	7/14[4]
Dexter Max	C	24	[7]
Dexter XCEL	C	24	[7]
Endura	W	12	7
Fixed coppers[3]	D	24/48	0
Fontelis	C	12	3

(continued)

PESTICIDE SAFETY: Onions *(continued)*

	Signal[1]	Re-entry (hrs)	Harvest (days)
Forum SC	C	12	0
Gavel	C	48	7
Inspire Super	C	12	7
Iprodione[3]	W	24	7
Luna Experience	C	12	7
Luna Tranquility	C	12	7
Mancozeb[3]	C	24	7
Mandipropamid[3]	C	4	7
ManKocide	D	24	7
Mefenoxam[3]	W	48	0
Metalaxyl[3]	C	48	0
Merivon	W	12	7
Miravis Prime	C	12	7
Muscle	C	12	7/14[4]
Omega 500F	W	48	7
Orondis Opti	D	12	7
Orondis Ultra	D	12	7
Presidio	C	12	2
Pristine	C	12	7
Propiconazole[3]	W	12	14
Quadris Opti	W	12	7
Quadris Top	C	12	7
Quilt	C	12	14
Ranman	C	12	0
Reason 500 SC	C	12	7
Ridomil Gold Bravo SC	W	48	7/21[4]
Ridomil Gold Copper[3]	D	48	7/10[4]
Ridomil Gold MZ	W	48	7
Scala	C	12	7
Sulfur[3]	C	24	0
Switch	C	12	7
Tanos	C	12	3
Tebuconazole[3]	C	12	7
Thiophanate-methyl[3]	C	72	-
Trivapro	W	12	14
Vangard	C	12	7
Zampro	C	12	0
Zing!	C	12	7

1 W: Warning, C: Caution, D: Danger; P: Poison
2 AP: At planting
3 Several formulations are marketed. See the general introduction for more details on fungicides.
4 Dependent on type of onion (green, bulb or dry), see label.

INSECT CONTROL: Onions[1]

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
PREPLANT/PLANTING			
Onion Maggots: Problems with onion maggots are often associated with soils that are high in organic matter or amended with manure. Continuous planting of onions on the same ground will increase onion maggot problems. When possible, rotate with other crops. Eliminate culls and volunteer onions after harvest to reduce the overwintering population.			
Diazinon 50 W	4 to 8 lb	8 lb	Incorporate immediately into top 3-4 inches of soil.
Malathion 8	1.5 pt	2 applications	For post-plant, allow 7 days between applications.
FOLIAR TREATMENTS			
Thrips: In general, red onions are more susceptible to thrips injury. Monitor for thrips regularly, especially during hot, dry weather. When needed, treat during early bulb stage and use 10 to 25 thrips per plant as a guideline for treatment.			
Admire Pro	14 fl oz	14 fl oz	Soil application only.
Agri-Mek 0.7 SC	1.75 to 3.5 fl oz	10.25 fl oz	Allow 7 days between applications. Must use a non-ionic surfactant.
Assail 30 SG	5 to 8 oz	32 oz	Limit 4 applications. Allow 7 days between applications.
Knack 0.83 EC	8 fl oz	16 fl oz	Target immatures. Limit 2 applications.
Lannate 90 SP	1 lb	4 lb	Limit 8 applications, allow 5 days between applications.
Movento 2 SC	5 fl oz	10 fl oz	For thrips larvae. Allow 7 days between applications. Requires surfactant.
Mustang Maxx	2.88 to 4 fl oz	20 fl oz	Allow 7 days between applications.
Permethrin 3.2 EC	6 to 12 fl oz	40 oz	Bulb onions only.
Proaxis 0.5 EC	2.56 to 3.84 fl oz	30.7 fl oz	Allow 5 days between applications. Bulb onions only.
Radiant SC	6 to 10 fl oz	30 fl oz	Allow 4 days between applications.
Requiem EC	1.5 to 3 qt		-
Scorpion 35SL	2 to 7 fl oz	10.5 fl oz	Allow 7 days between applications.
Torac 1.29 EC	24 fl oz	72 fl oz	Limit 3 applications. Allow 7 days between applications.
Venom 70 SG	3 to 4 oz	6 oz	Foliar application. Allow 7 days between applications.
	5 to 6 oz	6 oz	Soil application.
Verimark 1.76 SE	10 to 13.5 fl oz	61.5 fl oz	Soil application at planting.
	6.75 to 10 fl oz	61.5 fl oz	Drip application.
Warrior II	1.28 to 1.92 fl oz	15.36 fl oz	Bulb onion and garlic only.

1 Generic products available (Appendix G).

WEED CONTROL: Onion

Product Amt/A	lb A.I./A	Comments
0.5 to 1.6 fl oz Aim 1.9 EW	0.008 to 0.025 carfentrazone	For contact post-emergence control of annual broadleaf weeds and suppression of annual grasses. Can be applied as a preplant, pre-transplant burndown, or before crop emerges to actively growing weeds up to 4 inches tall. Can also be applied post-emergence as a directed hooded application between crop rows. Use min. 10 gal of water/A and crop oil 1% v/v. Max. rate 6.1 fl oz/A. PHI = 0 days.
1 to 1.5 pt Buctril	0.25 to 0.38 bromoxynil	For selective post-emergence control of broadleaf weeds in DRY BULB ONIONS. Use in 50 to 70 gal of water/A. Apply when both soil and onion leaves are dry and when temperature is 70 to 85°F. Apply to onions with 2 to 5 leaves and when weeds are < 2 inches tall. Do not add surfactant. Do not irrigate within 2 days of a pre-emergence application or within 3 days of crop emergence.
2 oz Chateau 51 WDG	0.064 flumioxazin	Apply to transplanted onions (dry bulb) between the 2-leaf and 6-leaf stage and on direct seed onions (dry bulb) between the 3-leaf and 6-leaf stage. Apply to weed-free onions (dry bulb) for pre-emergence control of the weeds listed. For use on all soil types with up to 5% organic matter. Do not apply more than 2 oz of Chateau WDG per acre during a single application. Do not apply more than 3 oz of Chateau WDG per acre during a single growing season. PHI = 45 days. Min. 14 days between applications.
6 to 14 lb Dacthal W-75	4.5 to 10.5 DCPA	For pre-emergence control of annual grasses and small-seeded broadleaves. Can be broadcasted over transplants. Can be applied up to 14 weeks after planting at 14 pt/A rate. Do not preplant incorporate.
0.67 to 1.3 pt Dual Magnum	0.64 to 1.25 s-metolachlor	See the "Dual Magnum 24(c) Label" section on page 15.
1 pt Fusilade-DX 2E	0.25 fluazifop-p	For selective post-emergence control of annual grasses and suppression of perennial grasses. Include 1% v/v crop oil or 0.25% v/v non-ionic surfactant/A. PHI = 45 days. Max. rate is 48 fl oz/A.

(continued on next page)

WEED CONTROL: Onion (continued)

Product Amt/A	lb A.I./A	Comments
0.5 pt Goal 2XL	0.12 oxyfluorfen	For pre-emergence control of certain annual grasses and most broadleaves on dry bulb onion only immediately after transplanting. Transplanted onions are most tolerant of a postemergence application immediately after transplanting. Do not exceed the maximum use rate of 2 pints per acre of Goal 2XL per season as a result of multiple applications.
2 to 4 pt Gramoxone Inteon	0.67 to 1.35 paraquat salt	For non-selective contact kill of annual grasses and broadleaf weeds and top-kill of perennial weeds. Apply preplant, pre-emergence, or before transplanting in min. 20 gal of water/A. Apply banded or broadcast. Use higher rate for heavy weed infestations. Use non-ionic surfactant 0.25% v/v. PHI = 60 days**. Paraquat product labels require applicators to take an EPA-approved training every 3 years to mix, load, and apply paraquat.**
10 to 21 fl oz Outlook 6 EC	0.47 to 0.98 dimethenamid-P	For pre-emergent control of select annual grasses and broadleaf weeds. Apply to onions after the 2 leaf stage and after soil has settled around transplanted onions, or injury may be severe. Can be applied in a single or split application. PHI = 30 days.
0.5 to 1.5 pt Poast 1.5 EC	0.09 to 0.27 sethoxydim	For control of actively growing grasses only. Use high rate on Johnson grass. PHI = 30 days. Max. rate of 1.5 pt/application and 4.5 pt/season.
5 to 6 qt Prefar 4 E	5 to 6 bensulide	For control of annual grasses and small-seeded broadleaves in DRY BULB ONIONS. Apply preplant incorporated to a depth of 1 inch or pre-emergence after planting. Irrigate immediately after pre-emergence application.
2 pt Prowl H2O	0.95 pendimethalin	For control of annual grasses and broadleaf weeds. The label allows use of 2 pints pre-emergence and 2 pints after the two leaf stage. A maximum of 4 pints (1.9 lb ai) may be applied per crop. It should not be used on soils with less than 3% OM. PHI = 30-days.
16 to 22 fl oz Roundup WeatherMax 5.5L	0.69 to 0.94 glyphosate-salt	For non-selective post-emergence control of annual and perennial grasses and broadleaf weeds. Use only AMS 1 to 2% v/v. Adding a non-ionic surfactant can reduce weed control effectiveness. Min. 30 days before planting any non-labeled crop.

DISEASE CONTROL: Onions—Dry and Spanish

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Bacterial Leaf Blight					
Actigard	21	7	0.75 to 1.0 oz	4 oz	Begin applications 2 to 4 weeks prior to bulb initiation and continue on 7 to 10 day interval. Include copper in spray program for best results.
Copper, fixed coppers[4]					See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
ManKocide[3]	M	7	1.5 to 2.25 lb	see footnote	
Botrytis Leaf Blight, Purple Blotch, Stemphylium Blight					
Ariston	M/27	7	1.6 - 2.4 pt	14 pt	Downy mildew and purple blotch.
Aprovia Top	7/3	7	10.5 oz	4 apps	Fungal leaf spots. Use a spreading/ penetrating surfactant.
Botran 75 W	14	14	1.66 to 3.33 lb	5.33 lb	Botrytis leaf blight.
Bravo and chlorothalonil[4] generics	M	7/14			There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Cabrio and pyraclostrobin[4] generics	11	7	8 to 12 oz[5]	6 apps	Use higher rates for downy mildew and Botrytis leaf blight.
Copper, fixed coppers[4]					Purple blotch and downy mildew. See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Dexter Max	M/11	7	3.2 lb	30 lb	Do not apply to exposed bulbs.
Dexter XCEL	M/11/3	7	48 to 72 oz	144 oz	Do not allow contact with bulbs.
Dithane M45, mancozeb[4] generics	M	7	3 lb	30 lb	Do not apply to exposed bulbs. There are multiple Dithane formulations and mancozeb generics on the market. See label for rates.
Endura	7	7	6.8 oz	6 apps	Purple blotch and botrytis leaf blight only.
Fontelis	7	3	16 to 24 fl oz	72 fl oz	
Gavel	22/M	7	1.5 to 2.0 lb	16 lb	Fungal leaf spots, also downy mildew. Do not apply to exposed bulbs.

(continued on next page)

DISEASE CONTROL: Onions—Dry and Spanish *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Inspire Super	3/9	7	16 to 20 fl oz	80 fl oz	Botrytis leaf blight, purple blotch.
Luna Experience	7/3	3	8.0 to 12.8 fl oz	34 fl oz	
Luna Tranquility	7/9	7	16 to 27 oz	54.7 oz	
ManKocide[3]	M	7	2.5 lb	see footnote	
Merivon	7/11	7	5.5 to 11 fl oz	3 apps	Use higher rates for downy mildew.
Miravis Prime	7/12	7	10.3 to 11.4 oz	34.2 oz	Use higher rate for downy mildew.
Muscle ADV	3/M	7/14	1.1 to 1.6 pt	6.4 pt	
Omega 500 and fluazinam[4] generics	29	7	16 fl oz	6 apps	Botrytis leaf blight, Botrytis neck rot, downy mildew, purple blotch. Do not use a spray adjuvant.
Orondis Opti	49	7	1.75 to 2.5 pt	10 pt	Do not combine with soil applications of Orondis Gold.
Pristine	7/11	7	14.5 to 18.5 oz	4 apps	Use lower rates for Botrytis leaf blight.
Quadris and azoxystrobin[4] generics	11	0	6 to 15.5 fl oz	90 fl oz	Use higher rates for downy mildew and Botrytis leaf blight. There are multiple Quadris formulations and azoxystrobin generics on the market. See label for rates.
Quilt Xcel and Propiconazole + azoxystrobin[4] generics	11/3	0	14 to 26 fl oz	56 fl oz	Use higher rates for downy mildew and Botrytis leaf blight.
Reason	11	7	5.5 fl oz	22 fl oz	Downy mildew and purple blotch.
Ridomil Gold Bravo SC	4/M	7/21	2.5 pt	4 apps	Avoid late-season applications.
Rovral and iprodione[4] generics	2	7	1 to 1.5 pt	5 app	Use lower rate if tank mixed. See label for rates and application instructions. Also labeled for white rot on garlic.
Scala	9	7	9 to 18 fl oz	54 fl oz	Purple blotch and botrytis leaf blight only.
Switch 62.5WG	9/12	7	11 to 14 oz	56 oz	Not for downy mildew.
Tanos	11/27	3	8 oz	84 oz	Downy mildew, purple blotch. Must be tank-mixed with a multi-site inhibitor (FRAC Group M).
Toledo and tebuconazole[4] generics	3	7	4 to 6 fl oz	12 fl oz	Purple blotch only. Use lowest listed rate of surfactant to improve coverage. Also labeled for white rot.
Tilt and Propiconazole[4] generics	3	14	2 to 8 fl oz	16 fl oz	Purple blotch and botrytis leaf blight. See label for specific rates.
Trivapro	3/11/7	14	16.0 to 27.7 oz	55.4 oz	
Vangard	9	7	10 oz	28 oz	
Viathon	3/33	7	2 to 3 pt	6 pt	
Zing!	M/22	7	30 fl oz	8 apps	Do not apply directly to bulbs.
Downy Mildew					
Actigard	21	7	0.75 to 1 oz	4 oz	Apply in a min of 20 gal/A of water. May cause phytotoxicity and yield reduction. Do not apply to stressed or injured plants.
Ariston	M/27	7	1.6 - 2.4 pt	14 pt	
Bravo and chlorothalonil[4] generics	M	7/14			See label for rates.
Cabrio and pyraclostrobin[4] generics	11	7	12 oz	6 apps	
Dithane M45 and mancozeb[4] generics	M	7	3 lb	30lb	There are multiple Dithane formulations and mancozeb generics on the market. See label for rates.
Forum SC	40	0	6 fl oz	5 apps	Must be tank-mixed with another downy mildew fungicide, excluding mefenoxam.
Gavel	22/M	7	1.5 to 2.0 lb	16 lb	Do not apply to exposed bulbs.
ManKocide[3]	M	7	2.5 lb		
Merivon	7/11	7	5.5 to 11 fl oz	3 apps	.
Omega 500 and fluazinam[4] generics	29	7	16 fl oz	6 apps	Do not use a spray adjuvant.
Orondis Opti	49/M	7	1.75 to 2.5 pt	10 pt	Do not combine with applications of Orondis Ultra.
Orondis Ultra	49/40	7	5.5 to 8.0 oz	32 oz	Do not combine with applications of Orondis Opti.

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DISEASE CONTROL: Onions—Dry and Spanish *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Presidio	43	2	3 to 4 fl oz	4 apps	Must be tank-mixed with a fungicide NOT in FRAC Group 43.
Quadris and azoxystrobin[4] generics	11	0	9 to 15.5 fl oz	90 fl oz	Use higher rates for downy mildew and Botrytis leaf blight.
Ranman	21	0	2.75 to 3.0 oz	16.5 oz	Use an organosilicone surfactant for best results.
Reason	11	7	5.5 fl oz	22 fl oz	
Revus	40	7	8 fl oz	32 fl oz	Use a spreader/penetrant surfactant. Must be tank-mixed with a fungicide NOT in FRAC Group 40.
Ridomil Gold Copper	4/M	7/10	2 lb	4 apps	Avoid late-season applications.
Ridomil Gold MZ[3]	4/M	7	2.5 lb		Avoid late-season applications.
Zampro	40/45	0	14 fl oz	3 apps	
Zing!	M/22	7	30 fl oz	8 apps	Do not apply directly to bulbs.
Pythium Damping-off, Cottony Leak					
MetaStar and metalaxyl[4] generics	4	0	2 to 4 pts		Preplant or transplant applications. See label for rate and application instructions. Do not use MetaStar in greenhouse or transplant beds.
Ridomil Gold and mefenoxam[4] generics	4	0	0.5 to 1 pt		

NOTE: Some of the chemicals listed above may not be labeled for green onions—check product labels carefully before use.

1 Products with numerical FRAC codes must be alternated or tank-mixed with products that have a different FRAC code to discourage resistance development. See product label for maximum number of consecutive applications allowed. Refer to the table on pages 22-24 for more information on FRAC codes.

2 Pre-harvest interval.

3 Observe seasonal limits for mancozeb.

4 Generic products available (Appendix F). Amounts and seasonal limits per acre are product dependent.

5 Use higher rate when pressure is severe.

Peas

Pea family (Fabaceae): *Pisum sativum*

Planting and Culture

Early spring plantings are a must to ensure good yields in Kentucky. The earliest plantings should be made between February 20 and March 1 or by the time the soil temperature has reached 45°F (see Appendix K). Use seed treatments to avoid decay problems.

Select soils that are well drained and adjust the pH to 6.5. Lighter, sandy loam soils are preferred because they warm up sooner.

Seed may be planted in either double or single rows. Double rows should be spaced 6 to 8 inches between rows and 18 to 24 inches between pairs of rows or adjusted to the cultivating equipment that is available. Plants in double rows will support each other. For tall-growing, indeterminate varieties, plant supports will need to be constructed. Space single rows 24 to 36 inches apart. Seed within the row should be planted 1 to 1½ inches deep and spaced 1 inch apart. Peas requires between 60 and 100 pounds of seed per acre, depending on spacing.

Harvesting

English peas should be picked as soon as pods are well filled but before they harden and fade in color. Two or three pickings can usually be made. Peas should be cooled and processed as soon as possible because the sugar content decreases rapidly after harvest. It is best to shell the peas just before cooking.

Edible pod or snow peas are harvested while the peas are immature. Pods reach a length of 3 to 5 inches within five to seven days after flowering. Consequently, pods should be harvested every other day to prevent the development of large seeds and tough pods. Edible pod peas in plastic bags will store 10 days under refrigeration without loss of quality.

Edible pod snap peas can be harvested from the time the peas begin to form until the pods are well filled.

Peas should be stored at 32° to 34°F and 90 to 95 percent relative humidity.

VARIETIES: Peas—English, Edible Pod, Snap

Variety	DTM[1]	Comments
ENGLISH (ALL ARE DETERMINATE)		
Spring	57	Large pods for an early cultivar; excellent quality; open pollinated.
Maestro	61	Heavy producer of 4 inch long pods; excellent quality; tolerance to *Fusarium*, pea enation virus, bean yellow mosaic virus, and powdery mildew.
Legacy	67	Productive, 3.5 inch pods; 2.5 pods per node; resistant to *Fusarium* and powdery mildew.
Green Arrow	68	Productive, *Fusarium* and powdery mildew resistant.
EDIBLE POD[2]		
Oregon Giant	69	Highly productive; sweet pods 4 inches long; resistant to *Fusarium*, pea enation mosaic virus and powdery mildew.
Oregon Sugar Pod II	70	Highly productive; pods 3 inches long; *Fusarium* resistance.
Mammoth Melting Sugar	74	Vine 34 to 40 inches tall, pods 4 inches long.
SNAP		
Sugar Ann	56	Resistant to *Fusarium* race 1, very sweet.
Sugar Sprint	62	Stringless, 3 inch pods; powdery mildew resistant, pea enation virus tolerance.
Cascadia	67	Very productive; 3 inch long pods; pods remain tender and sweet longer than other cultivars; very good disease tolerance.
SL3123	70	Concentrated set, tolerant to stress, stringless.
Sugar Snap	72	Resistant to common pea wilt; an All American Selection all time winner; must be trellised; very heavy yielder.

1 Days to maturity
2 P. sativum var. macrocarpon

FERTILIZER: Peas

Soil Test Results (lb/A)		Fertilizer Needed (lb/A)
Phosphorus		**Phosphate (P_2O_5)**
Low	<31	121-180
Medium	31-60	61-120
High	61-80	1-60
Very High	>81	0
Potassium		**Potash (K_2O)**
Low	<201	101-200
Medium	201-300	51-100
High	301-450	1-50
Very High	>450	0
Nitrogen		**N**
Poor soils		50-60
Fertile soils		30-40

PESTICIDE SAFETY: Peas

	Signal[1]	Re-entry (hrs)	Harvest (days)
INSECTICIDES			
Acramite 4 SC	C	12	3
Admire Pro	C	12	7/21[3]
Assail 30 SG	C	12	7[3]
Beleaf 50 SG	C	12	7
Blackhawk 36 WG	C	4	3/28[3]
Bt products	C	4/12	0
Coragen 1.67 SC	-	4	1
Dimethoate 4 E	W	48	0
Exirel 0.83 SE	C	12	1/7[3]
Knack 0.86 EC	C	12	7
Intrepid 2 F	C	4	7
Magister SC	W	12	7
Malathion 8	C	12	3
Movento 2 SC	C	24	1/7[3]
Radiant SC	C	4	3/28
Sevin XLR Plus	W	12	3
Sivanto Prime 1.67 SL	C	4	7
Verimark 1.67 SC	-	4	AP
Restricted Use			
Agri-Mek 0.7 SC	W	12	7
Asana XL	W	12	3/21[3]
Baythroid XL	W	12	7

(continued)

PESTICIDE SAFETY: Peas *(continued)*

	Signal[1]	Re-entry (hrs)	Harvest (days)
Brigade 2 EC	W	12	3
Danitol 2.4 EC	W	24	7[3]
Diazinon 50 W	C	24	7
Fastac 0.83 EC	D	12	1/21[3]
Lannate 90 SP	DP	48	1[3]
Mustang Maxx	W	12	1/21[3]
Proaxis 0.5 EC	C	24	7/21[3]
Warrior II	W	24	7/21[3]
FUNGICIDES			
Azoxystrobin[2]	C	4/48[4]	0
Fixed coppers[2]	D	24/48[4]	0
Endura	W	12	7/21[3]
Fontelis	C	12	0
Headline[3]	W	12	7/213
Kenja	C	12	7/14/30[3]
Luna Experience	C	12	14
Metalaxyl[2]	W	48	0
Mefenoxam[2]	C	48	0
Priaxor	C	12	7
Sulfur[2]	C	24	0

1 W: Warning, C: Caution, D: Danger; P: Poison
2 Several formulations are marketed. See the general introduction for more details on fungicides.
3 PHI depends on the type of pea, see label.
4 Depends on type of application and product.

INSECT CONTROL: Peas[1]

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
PREPLANT INCORPORATED			
Cutworms, Wireworms: Eliminate weeds from field margins and plow fields at least 2 weeks before planting to destroy cutworm food sources and egg laying sites. Wireworms can be a potential problem where peas follow grass or grass-legume sod.			
Diazinon 50 W	4 to 8 lb	1 application	Incorporate immediately before planting.
PLANTER BOX			
Seedcorn Maggots: Usually only a serious pest early in the season. Shallow planting in well-prepared seedbeds and adequate soil temperature to promote rapid germination will aid in reducing problems. Heavy cover crops or manure should be plowed early to render fields less attractive for egg laying.			
FOLIAR TREATMENTS			
Alfalfa Loopers, Green Cloverworms			
Asana XL	2.9 to 9.6 fl oz	19.2 fl oz	Do not feed vines.
Blackhawk 36 WG	2.2 to 3.3 oz	20 oz	Allow 5 days between applications.
Bt products	See labels.	-	-
Brigade 2 EC	2.1 to 6.4 fl oz	12.8 fl oz	Allow 3 to 7 days between applications.
Fastac 0.83 EC	2.7 to 3.8 fl oz	11.4 fl oz	Allow 5 days between applications.
Intrepid 2 F	4 to 16 fl oz	64 fl oz	Allow 7 days between applications. Limit 4 applications.
Lannate 90 SP	0.25 to 1 lb	3 lb	Wait 5 days to feed forage. Succulent peas only.
Mustang Maxx	2.72 to 4 fl oz	24 fl oz	Allow 5 days between applications.
Proaxis 0.5 EC	1.92 to 3.84 fl oz	15.36 fl oz	-
Warrior II	0.96 to 1.92 fl oz	7.68 fl oz	-
Aphids			
Admire Pro	7 to 10.5 fl oz	10.5 fl oz	Soil application.
	1.2 fl oz	3.6 fl oz	Foliar application. Allow 7 days between applications.

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INSECT CONTROL: Peas[1] *(continued)*

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Assail 30 SG	2.5 to 5.3 oz	16 oz	Limit 3 applications. Allow 7 days between applications. Not for dried peas.
Beleaf 50 SG	2.8 oz	8.4 oz	Limit 3 applications. Allow 7 days between applications.
Brigade 2 EC	2.1 to 6.4 fl oz	12.8 fl oz	Allow 3 to 7 days between applications.
Malathion 8	1 pt	2 applications	Allow 7 days between applications. Do not feed vines.
Movento 2 SC	4 to 5 fl oz	10 fl oz	Allow 7 days between applications. Requires surfactant.
Sivanto Prime 1.67 SL	7 to 14 fl oz	28 fl oz	Allow 10 days between applications.
Armyworms, Cutworms			
Asana XL	5.8 to 9.6 fl oz	19.2 fl oz	Do not feed vines.
Baythroid XL	0.8 to 3.2 fl oz	6.4 fl oz	Dry peas only. Limit 3.2 fl oz per 14-day period.
Blackhawk 36 WG	2.2 to 3.3 oz	20 oz	Allow 5 days between applications.
Brigade 2 EC	2.1 to 6.4 fl oz	12.8 fl oz	Allow 3 to 7 days between applications.
Coragen 1.67 EC	3.5 to 7.5 fl oz	15.4 fl oz	Allow 3 days between applications.
Fastac 0.83 EC	1.3 to 3.8 fl oz	11.4 fl oz	Allow 5 days between applications.
Intrepid 2 F	4 to 16 fl oz	64 fl oz	Allow 7 days between applications. Limit 4 applications.
Mustang Maxx	2.72 to 4 fl oz	24 fl oz	Allow 5 days between applications.
Proaxis 0.5 EC	1.92 to 3.84 fl oz	15.36 fl oz	-
Sevin XLR Plus	1 to 1.5 qt	6 qt	Limit 4 applications. Allow 7 days between applications.
Warrior II	1.28 to 1.92 fl oz	7.68 fl oz	-

1 Generic products available (Appendix G).

WEED CONTROL: Peas

Product Amt/A	Lb A.I./A	Comments
0.5 to 1.6 fl oz Aim 1.9 EW	0.008 to 0.025 carfentrazone	For contact post-emergence control of annual broadleaf weeds and suppression of annual grasses. Can be applied as a preplant, pre-transplant burndown or before crop emerges to actively growing weeds up to 4 inches tall. Can also be applied post-emergence as a directed hooded application between crop rows. Use min. 10 gal of water/A and crop oil 1% v/v. Max. rate 6.1 fl oz/A. PHI = 0 days.
1 to 2 pt Basagran 4S	0.5 to 1 bentazon	For post-emergence control of annual broadleaves and suppression of yellow nutsedge. Two applications are needed for nutsedge and Canada thistle control. Do not add crop oil. Apply after peas have at least 3 pairs of leaves (or 4 nodes) or severe crop damage may occur. PHI for dry peas is 30 days and for succulent peas is 10 days. Do not apply when peas are in bloom.
1.3 pt Command 3ME	0.5 clomazone	For pre-emergence control of annual grasses and broadleaf weeds. Apply once in a min. 10 gal of water/A. Apply and incorporate 2 to 3 inches before planting. Use in combination with other herbicides to broaden weed control spectrum.
1.3 to 1.7 pt Dual II Magnum 7.6 E	1.3 to 1.6 s-metolachlor	For control of most annual grasses and certain broadleaves. Apply preplant surface or incorporated or pre-emergence. Small grains may be planted 4½ months following this treatment. See label for other rotational crops.
2 to 4 pt Gramoxone Inteon	0.69 to 1.38 paraquat salt	For non-selective contact kill of annual grasses and broadleaf weeds and top-kill of perennial weeds. Apply preplant, pre-emergence, or before transplanting in min. 10 gal water/A. Apply banded or broadcast. Use higher rate for heavy weed infestations. Use non-ionic surfactant 0.25% v/v. **Paraquat product labels require applicators to take an EPA-approved training every 3 years to mix, load, and apply paraquat.**
0.5 to 2.5 pt Poast 1.5	0.09 to 0.48 sethoxydim	For control of actively growing grasses only. Use high rate on Johnson grass. Dry and succulent peas. Max. rate 4 pt/A per year. Include 1% v/v crop oil. PHI = 15 days for succulent peas and 30 days for dry peas.
3 oz Pursuit 2L	0.05 imazethapyr	For control of annual grasses and broadleaf weeds. Can be applied preplant incorporated within 1 week before planting. Can be applied pre-emergence within 3 days after planting. Can be applied post-emergence to plants at least 3 inches tall but before 5 nodes and before flowering. Add non-ionic surfactant 0.25% v/v.
16 to 22 fl oz Roundup WeatherMax 5.5L	0.69 to 0.94 glyphosate-salt	For non-selective post-emergence control of annual and perennial grasses and broadleaf weeds. Use only AMS 1 to 2% v/v. Adding a non-ionic surfactant can reduce weed control effectiveness. Min. 30 days before planting any non-labeled crop.
6 to 12 oz Targa	0.04 to 0.08 quizalofop p-ethyl	See label for pea type. Apply post-emergence to weeds up to 3" when peas are at least 3" high, but prior to 5 nodes and before flowering. Add non-ionic surfactant at 2 pt per 100 gal of spray mix. See label for crop rotation restrictions. PHI = 30 days.
1 to 2 pt Treflan HFP 4 E	0.5 to 1 trifluralin	For control of annual grasses and broadleaf weeds. Apply and incorporate in spring before planting or in fall in advance of spring planting.

DISEASE CONTROL: Peas

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Anthracnose, Ascochyta Leaf Spot/Pod Blight, Leaf Spots, Powdery Mildew					
Copper, fixed coppers	M	0			See label for rates, mixing instructions, and tank-mix precautions.
Endura	7	7/21	6 to 11 oz	2 apps	
Fontelis	7	0	14 to 30 fl oz	72 fl oz	
Headline and pyraclostrobin[4] generics	11	7/21	6 to 9 fl oz	18 fl oz	PHI differs for dried peas and edible-podded peas.
Kenja	7	7/14/30	17 oz	34 oz	White mold/gray mold. Make first application at 10-30% bloom.
Luna Experience	7/3	14	8.0 to 12.8 fl oz	25.6 fl oz	
Priaxor	7/11	7	4 to 8 fl oz	16 fl oz	
Quadris and azoxystrobin[4] generics	11	0			There are multiple Quadris formulations and azoxystrobin generics on the market. See label for rates.
Sulfur[4]	M				Powdery mildew. Apply when disease is first observed; continue every 14 days as needed. Phytotoxicity may occur if applications are made when temperatures exceed 90°F. Some products are OMRI-listed; refer to labels.
Pythium Damping-off, Root Rot					
Metalaxyl[4] Mefenoxam[4]	4	0		1 app	Apply pre- or post-planting as a broadcast or banded spray (7-inch band) in sufficient water to provide uniform coverage. Incorporate into the upper 2 inches of soil mechanically or by rainfall/irrigation.
Uniform	4/11	-	0.34 fl oz/ 1,000 row ft	1 app	In-furrow spray at sowing. Avoid direct contact with seed for best results.
Rhizoctonia Damping-off, Seedling Disease, Stem/Root Rot					
Quadris and azoxystrobin[4] generics	11	0			In-furrow spray at sowing.
Uniform	4/11	-	0.34 fl oz/ 1,000 row ft	1 app	In-furrow spray at sowing. Avoid direct contact with seed for best results.

1 Products with numerical FRAC codes must be alternated or tank-mixed with products that have a different FRAC code to discourage resistance development. See product label for maximum number of consecutive applications allowed. Refer to the table on pages 22-24 for more information on FRAC codes.

2 Pre-harvest interval.

3 Per 1,000 row-feet.

4 Generic products available (Appendix F). Amounts and seasonal limits per acre are product dependent.

5 Use higher rate when pressure is severe.

Peppers

Nightshade family (Solanaceae): *Capsicum annuum*

For information on peppers see "Fruiting Vegetables" section on page 86

Potatoes

Nightshade family (Solanaceae): *Solanum tuberosum*

Potatoes are grown in Kentucky as an early crop primarily for fresh market sales. Opportunity exists for the production of small red "new potatoes," russets, heirlooms, and other specialty or "gourmet" types for local markets, sales to restaurants, or sales to local/area wholesalers. Sales of very small "baby" or "mini" potatoes are also possible and command premium prices in some markets.

Planting and Culture

Loam soils are most desirable for good potato yields, though potatoes can be grown on a wide range of soil types. Select a well-drained soil. Sod ground should be treated with a soil insecticide prior to planting to control grubs and wireworms.

Optimum planting times are from March 15 to April 10 for early potatoes and from June 15 to July 15 for a late crop (see Appendix K).

Planting should be made in rows 30 to 36 inches apart with a seed piece dropped each 10 to 12 inches in the furrow. Seed planted in mid-March should be planted 2 to 3 inches deep. The late crop should be planted 4 to 5 inches deep. Seed pieces should be 1½ to 2 ounces in size. Only certified disease-free seed stock should be purchased. Freshly cut seed should be planted as soon as possible after cutting. Seed may be pre-cut several days in advance of planting if proper storage conditions are provided so the seed pieces can "heal over." A storage temperature of 60°F for 10 days to two weeks before planting will help initiate sprout activity and encourage more rapid emergence.

Fifteen to 18 (100-pound) bags of seed potatoes are usually needed to plant an acre. Potatoes should not follow potatoes or other solanaceous crops (tomatoes, tobacco, peppers) on the same ground year after year. Follow a three- or four-year rotation program.

When planting, there will be a small ridge of soil developed over each row. Dragging across the ridges just before the sprouts break through helps to eliminate weeds and allows the potato sprouts to more easily break through compacted soil.

Production with Plasticulture

Potatoes can also be grown on raised beds with black plastic and drip irrigation. Growers have obtained higher and earlier yields of better quality potatoes with plasticulture; potatoes grown on plastic mulch are also easier to dig by hand at harvest. If mechanical harvesting or growing large acreages, plastic mulch should be avoided.

All fertilizer can be applied prior to planting or half the nitrogen requirement can be applied before planting with the remainder divided into equal doses fertigated weekly. Planting holes can be made in plastic mulch using a waterwheel setter and seed pieces dropped in the holes and covered with soil by hand. Kentucky growers have used two rows per bed with 18 inches between rows, 9 to 12 inches between plants within the rows, and 5 feet between bed centers. Pennsylvania growers have used double rows 13 inches apart with 8 inches between plants in the rows. Closer spacings promote higher percentages of smaller tubers and should be used to produce potatoes to be sold as "new," "gourmet," "baby," or "mini" (see also "Harvesting and Handling" below). Vine killing can be more problematic for some specialty potato varieties. In addition to chemical dessicants, a plastic mulch lifter can be used to undercut the plants to assist in vine killing prior to digging.

Fertilizing

Fertilize and lime based on soil test results; a soil pH of 6.0 to 6.5 is considered most desirable for maximum availability of nutrients for potatoes. However, potato scab will usually be more serious at high pH levels. There will normally be less scab when the pH is between 5.0 to 5.2. Potatoes grown for chipping should be grown at the higher pH and those for fresh market at the lower pH if scab is a problem.

It is suggested that one-half the fertilizer used at planting be broadcast prior to planting and disked in. Band the remaining fertilizer 2 to 3 inches to the side and slightly below the seed piece. Fertilizer should not come in contact with the seed piece. Sidedress with 50 to 75 pounds of actual nitrogen (N) per acre when plants are 4 to 8 inches tall or at lay-by.

Harvesting and Handling

When to dig potatoes will depend on the price and method of selling. For local market, it may be desirable to dig before vines die back. Vines of potatoes grown for storage should be dead before digging. Potatoes dug when immature are very susceptible to skinning and bruising. Using chemical desiccants to artificially kill the plant tops will aid in earlier harvest and promote a firmer skin set. Growers often mow plants prior to harvest. Harvesters or diggers should have digger chain speed adjusted to minimize injury to tubers. Protect freshly dug potatoes from hot sun and drying winds.

Smaller-sized "new," or "gourmet," potatoes are often dug by hand.

If tablestock potatoes are to be stored and kept for long periods, the storage facility should be clean and sanitized. Potatoes should be held at 55°F for two weeks at a relative humidity of 90 percent, and then the temperature should be lowered to 40°F with a relative humidity of 85 to 90 percent.

Washing potatoes for fresh market is desirable. Chlorine at the rate of 150 to 200 parts per million should be added to the water to help destroy surface disease organisms. Potato tubers should dry before bagging, especially into plastic, to reduce chances of bacterial soft rot. Do not wash potatoes going into storage.

Sprouting in storage can be reduced by spraying potato plants while still in the field with maleic hydrazide. Apply to the plants when tubers are 1½ to 2 inches in diameter. Read the product label for directions and precautions.

Potatoes are marketed in a variety of containers with several grade specifications. Russet potatoes are usually packed in consumer packs, count cartons, or large institutional packs. The most valuable potatoes are generally 8- to 14-ounce tubers packed in 50-pound cardboard boxes, or "count cartons." Each carton has a number that tells how many tubers are in a box. These are sold to retail stores and restaurants and are typically used for baking. Red and white potatoes are sold in a wider range of sizes per container ("non-size" Grade A) including 5-, 8-, 10-, and 50-pound plastic, poly mesh, paper, and burlap bags. Prices for 50-pound cartons of graded U.S. No. 1 potatoes can triple those for 50-pound bags of U.S. No. 1 non-size potatoes.

New potatoes are usually B size (1½ to 2¼ inches in diameter) tubers, while "gourmet," "baby," or "creamer" potatoes may be even smaller (1 to 1½ inches in diameter). Fingerling potatoes are sorted by length and range from 2 to 3½ inches long. Specialty potatoes are often sold for premium prices and are packed in small mesh bags, vented poly bags, baskets, cartons, tray packs, or clamshells.

VARIETIES: Potatoes

Maturity	Variety	Comments
Early	Dark Red Norland	Red skinned, shallow eyes—very suitable for table and "new" potatoes.
	Red Gold	Light red skin, yellow flesh, good yields of high quality tubers, not suitable for long term storage; some resistance to scab.
Early-midseason	Superior	White skinned, resistance to scab, tubers are oval to oblong, suitable for table use and chipping.
	Yukon Gold	Yellow flesh, round, smaller size, nice appearance and flavor, performance variable across state.
	Red Pontiac	Red skinned, readily available, easy to grow.
Midseason	Kennebec	White skinned, a good general purpose potato, best full season yields in KY.
	Russett Norkotah	White russet type, good baking-type potato.
	Red Lasoda	Red skinned, heat tolerant, readily available, not as attractive as some other red types.
FINGERLING TYPES		
Early-midseason	Russian Banana	White skin, light yellow flesh, long, thin shape, unique taste.
	Swedish Peanut	White skin, golden yellow flesh, shorter, teardrop shapes with shallow eyes, unique taste.

FERTILIZER: Potatoes

Soil Test Results (lb/A)		Fertilizer Needed (lb/A)
Phosphorus		**Phosphate (P_2O_5)**
Low	<31	181-240
Medium	31-60	91-180
High	61-80	61-90
Very High	>80	60
Potassium		**Potash (K_2O)**
Low	<201	251-300
Medium	201-300	101-250
High	301-450	51-100
Very High	>450	50
Nitrogen		**N**

Total of 150 lb N/A is recommended. Apply 75 to 100 lb N/A at time of planting and apply a sidedressing of 50 to 75 lb N/A when plants are 4 to 8 inches tall or at lay-by.

PESTICIDE SAFETY: Potatoes

	Signal[1]	Re-entry (hrs)	Harvest (days)[2]
INSECTICIDES			
Acramite 4 SC	C	12	14
Actara 25 WDG	C	12	14
Admire Pro	C	12	AP/7[5]
Assail 30 SG	C	12	7
Avaunt eVo 30 WDG	C	12	7
Belay 2.13SC	C	12	14
Beleaf 50 SG	C	12	7
Coragen 1.67 SC	-	4	14
Dimethoate 4 E	W	48	0[4]
Exirel 0.83 SE	C	12	7
Fulfill 50 WDG	C	12	14
Harvant 50 SL	C	4	7
Imidan 70 WP	W	24	7
Knack 0.83 EC	C	12	3
Malathion 8	C	12	0
Miteus 0.42 EC	W	12	7
Movento 2	C	24	7
Nurizma 2.5 SC	C	12	AP
Oberon 2 SC	C	12	7
Platinum 2 SC	C	12	AP
Portal XLO 0.4 EC	W	12	7
PQZ 1.87 SC	C	12	14
Radiant SC	C	4	7
Requiem 25 EC	C	4	0
Rimon 0.83 EC	W	12	14
Scorpion 3.5 SL	C	12	AP/7[5]
Sefina 0.42 SC	C	12	7
Sevin XLR Plus	W	12	7
Sivanto 1.67 SL	C	12	7
Torac 1.29 EC	W	12	14
Trident	C	4	0
Transform 50 WG	D	24	7
Vantacor 50 WG	-	4	14
Venom 70 SG	C	12	7[5]
Verimark 1.67 SC	-	4	AP
Restricted Use			
AgriMek 0.15 EC	W	12	14
Asana XL	W	12	7
Baythroid XL	W	12	0
Brigade 2 EC	W	12	21
Fastac 0.83 EC	W	12	1
Lannate 90 SP	DP	48	6
Mocap 15 G	DP	48	AP
Mustang Maxx	W	12	1
Permethrin 3.2 EC	C	12	14
Regent 4 SC	W	0	90
Thimet 20 G	DP	48	90
Vydate L	DP	48	7
Warrior II	W	24	7
FUNGICIDES			
Ariston	C	12	14
Azoxystrobin[4]	C	4	0
Blocker Flowable/4F	C	12	0
Botran	C	12	-

(continued)

PESTICIDE SAFETY: Potatoes *(continued)*

	Signal[1]	Re-entry (hrs)	Harvest (days)[2]
Cabrio Plus	C	24	14
Chlorothalonil[3]	D	12	7
Curzate 60 DF	W	12	14
Dexter Max	C	24	14
Elatus	C	12	14
Elumin	C	12	n/a
Endura	W	12	30
Evito 480 SC	C	12	7
Fixed coppers[3]	D	12/24[4]	0
Flint Extra	C	12	7
Fluazinam[4]	W	48	14
Fluoxastrobin[4]	C	12	7
Forum SC	C	12	4
Gavel 75 DF	C	48	14
Gem	C	12	7
Headline	W	12	3
Iprodione[4]	C	12	14
Luna Tranquility	C	12	7
Mancozeb[3]	C	24	14
Mefenoxam[4]	C	48	14
Metalaxyl[4]	C	48	14
Miravis Prime	C	12	14
Orondis Gold	C	4	14
Orondis Opti	D	12	7
Orondis Ultra	C	4	14
Previcur Flex	C	12	14
Priaxor	C	12	7
Provysol	C	12	7
Quadris Opti	W	12	14
Quadris Top	C	12	14
Quash	C	12	1
Ranman	C	12	7
Reason 500 SC	C	12	14
Revus	C	4	14
Revus Top	C	12	14
Ridomil Gold Bravo SC	W	48	14
Ridomil Gold Copper	D	48	14
Ridomil Gold MZ	C	48	14
Streptomycin[4]	C	12	n/a
Scala	C	12	7
Sulfur[3]	C	24	0
Tanos	C	12	14
Thiophanate-methyl[3]	C	12	21
Velum	C	12	7
Vertisan	W	12	7
Zampro	C	12	4
Zing!	C	12	7

1 W: Warning, C: Caution, D: Danger; P: Poison
2 AP: At planting
3 Several formulations are marketed. See the general introduction for more details on fungicides.
4 Safety information varies by product; read the label carefully.
5 PHI dependent on application method.

INSECT CONTROL: Potatoes[1]

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
AT PLANTING SOIL APPLICATION			
Wireworms, Flea Beetles, Colorado Potato Beetle, Aphids: Do not use a foliar spray of Actara, Assail, Belay, Provado, or Venom following a soil application of Admire, Belay, Platinum, or Venom.			
Admire Pro	5.7 to 8.7 fl oz	8.7 fl oz	For Colorado potato beetle, aphids, leafhoppers, and flea beetles.
Belay 2.13 SC	9 to 12 fl oz	12 fl oz	At planting or cultivation. Discontinue after 50% row cover.
Brigade 2 EC	9.6 to 19.2 fl oz	32 fl oz	Limit 2 applications. Allow 7 days between applications.
Mocap 15 G	1.4 lb/ 1000 row-feet	6 lbs/A	Limit one application. Incorporate immediately. Use at planting only.
Nurizma 2.5 SC	0.08 to 0.16 fl oz/ 1000 row-feet	At planting	Apply only as a 5-7" band at planting and cover completely with soil. For control of wireworms and white grubs.
Platinum 2 SC	5 to 8 fl oz	8 fl oz	Limit one soil application..
Regent 4 SC	3.2 fl oz	3.2 fl oz	In-furrow use only as a 5 to 7 inch band for wireworm. Do not band on surface.
Thimet 20 G	11.3 oz/ 1,000 row-feet	1 application	Not for flea beetles. Must incorporate granules.
Scorpion 35 SL	11.5 to 13.25 fl oz	13.25 fl oz	For Colorado potato beetle, leafhoppers, and flea beetles.
Verimark 1.67 SC	6.75 to 13.5 fl oz	13.5 fl oz	For Colorado potato beetle.
Venom 70 SG	6.5 to 7.5 oz	7.5 oz	For Colorado potato beetle, leafhoppers, and flea beetles.
FOLIAR TREATMENTS			
Grasshoppers			
Asana XL	5.8 to 9.6 fl oz	67.2 fl oz	-
Coragen 1.67 SC	2 to 5 fl oz	15.4 fl oz	Limit 4 applications. Allow five days between applications.
Dimethoate 4 E	0.5 to 1 pt	2 pt	Allow 7 days between applications.
Fastac 0.83 EC	3.2 to 3.8 fl oz	11.4 fl oz	Allow 4 days between applications.
Mustang Maxx	3.2 to 4 fl oz	24 fl oz	Allow 4 days between applications.
Warrior II	1.28 to 1.92 fl oz	7.68 fl oz	Allow 7 days between applications.
European Corn Borer			
Asana XL	5.8 to 9.6 fl oz	67.2 fl oz	-
Baythroid XL	1.6 to 2.8 fl oz	16.8 fl oz	Allow 5 days between applications.
Coragen 1.67 SC	3.5 to 7.5 fl oz	15.4 fl oz	Limit 4 applications. Allow five days between applications.
Exirel 0.83 SC	7 to 13.5 fl oz	61.5 fl oz	Allow 5 days between applications.
Fastac 0.83 EC	1.8 to 3.8 fl oz	11.4 fl oz	Allow 4 days between applications.
Mustang Maxx	1.76 to 4 fl oz	24 fl oz	Allow 4 days between applications.
Permethrin 3.2 EC	4 to 8 fl oz	32 fl oz	Allow 10 days between applications,
Radiant SC	6 to 8 fl oz	32 fl oz	Allow 7 days between applications. Limit 4 applications.
Rimon 0.83 EC	6 to 12 fl oz	24 fl oz	Allow 7 days between applications.
Warrior II	1.28 to 1.92 fl oz	7.68 fl oz	Allow 7 days between applications.
Colorado Potato Beetle, Flea Beetle: Colorado Potato Beetle is the key insect pest of potato. This pest has the ability to develop resistance to all major classes of insecticides. Do not tank mix insecticides with the same mode of action and frequently rotate among insecticides with different modes of action to discourage resistance. Treat when an average of more than 1 larva/adult is found per plant on plants less than 6 inches tall or when 2 or more larvae/adults are found on larger plants. [PB] IRAC Codes: Insecticides followed by the same number share the same mode of action.			
Actara 25 WDG (4A)	1.5 to 3 oz	6 oz	Allow 14 days between applications.
Admire Pro (4A)	1.3 fl oz	3.9 fl oz	Allow 7 days between treatments.
Agri-Mek 0.7 SC (6)	1.75 to 3.5 fl oz	10.25 fl oz	Make no more than two consecutive applications. Allow 7 days between applications.
Assail 30 SG (4A)	1.5 to 4 oz	16 oz	Limit 4 applications. Allow 7 days between applications.
Avaunt eVo 30 WDG (22)	3.5 to 6 oz	24 oz	Allow 5 days between applications. Limit 4 applications.
Belay 2.13 SC (4A)	2 to 3 fl oz	12 fl oz	Allow 7 days between applications. Do not apply after 50% row closure.
Coragen 1.67 SC (28)	3.5 to 7.5 fl oz	15.4 fl oz	Limit 4 applications. Allow five days between applications.
Exirel 0.83 SC (28)	5 to 13.5 fl oz	61.5 fl oz	Allow 5 days between applications.
Imidan 70 W (1B)	1.33 lb	6.67 lb	Machine harvested potatoes only. Allow 10 days between applications.
Radiant SC (5)	4.5 to 8 fl oz	32 fl oz	Allow 7 days between applications. Limit 4 applications.
Rimon 0.83 EC (15)	9 to 12 fl oz	24 fl oz	Allow 7 days between applications.

(continued on next page)

INSECT CONTROL: Potatoes[1] *(continued)*

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Scorpion 35 SL (4A)	2 to 2.75 fl oz	8 fl oz	Allow 14 days between applications.
Sevin XLR Plus (1A)	1 to 2 lb	6 qt	Allow 7 days between applications.
Sivanto Prime 1.67 SL (4D)	10.5 to 14 fl oz	28 fl oz	Allow 7 days between applications.
Torac 1.29 EC (21A)	14 to 21 fl oz	42 fl oz	Allow 14 days between applications. Limit 2 applications
Trident (11A)	3 to 6 qt	-	-
Venom 70 SG (4A)	1 to 1.5 oz	4.5 oz	Allow 14 days between applications.
Leafhoppers			
Actara 25 WDG	1.5 to 3 oz	6 oz	Allow 14 days between applications.
Admire Pro	1.3 fl oz	3.9 fl oz	Allow 7 days between treatments.
Asana XL	2.9 to 5.8 fl oz	67.2 fl oz	-
Assail 30 SG	1.5 to 4 oz	16 oz	Limit 4 applications. Allow 7 days between applications.
Baythroid XL	0.8 to 1.6 fl oz	16.8 fl oz	Allow 5 days between applications.
Belay 2.13 SC	2 to 3 fl oz	12 fl oz	Allow 7 days between applications. Do not apply after 50% row closure.
Dimethoate 4 E	0.5 to 1 pt	2 pt	Allow 7 days between applications.
Fastac 0.83 EC	1.8 to 3.8 fl oz	11.4 fl oz	Allow 4 days between applications.
Mustang Maxx	1.76 to 4 fl oz	24 fl oz	Allow 4 days between applications.
Permethrin 3.2 EC	4 to 8 fl oz	32 fl oz	Allow 10 days between applications.
Scorpion 35 SL	2 to 2.75 fl oz	8 fl oz	Allow 14 days between applications.
Sevin XLR Plus	1 to 1.5 qt	6 qt	Allow 7 days between applications.
Sivanto Prime 1.67 SL	7 to 14 fl oz	28 fl oz	Allow 7 days between applications.
Torac 1.29 EC	14 to 21 fl oz	42 fl oz	Allow 14 days between applications. Limit 2 applications
Transform 50 WG	1.5 to 2.25 oz	8.5 oz	Allow 7 days between applications. Limit 4 applications.
Venom 70 SG	1 to 1.5 oz	4.5 oz	Allow 14 days between applications.
Warrior II	0.96 to 1.6 fl oz	7.68 fl oz	Allow 7 days between applications.

1 Generic products available (Appendix G).

WEED CONTROL: Potato

Product Amt/A	lb A.I./A	Comments
1.5 to 2.9 pt Boundary 6.5 EC	0.98 to 1.9 s-metolachlor + 0.23 to 0.43 metribuzin	For control of most annual grasses and certain broadleaf weeds and yellow nutsedge. Apply after planting or after drag-off but before crop emergence. See Dual Magnum label for rotational crops restrictions. Dual Magnum may delay maturity and/or reduce yield of Superior and other early maturing potato varieties if cold, wet soil conditions occur after treatment. PHI = 60 days.
1 to 2 pt Dual II Magnum 7.6 E	0.95 to 1.9 s-metolachlor	For control of most annual grasses and certain broadleaf weeds and yellow nutsedge. Apply preplant incorporated, pre-emergence. Dual Magnum may delay maturity and/or reduce yield of 'Superior' and other early maturing potato varieties if cold, wet soil conditions occur after treatment. See label for incorporation directions. 60-day pre-harvest interval.
3.5 pt Eptam 7 E	3 EPTC	For control of annual grasses and broadleaf weeds and suppression of yellow nutsedge. Apply before planting. Incorporate immediately 2 to 3 inches. Superior variety is sensitive to Eptam under stress conditions.
1 to 2 pt Gramoxone Inteon	0.69 to 1.38 paraquat salt	For non-selective contact kill of annual grasses and broadleaf weeds and top-kill of perennial weeds. Apply up to ground cracking to emerged weeds but before crop emergence; may be used instead of drag-off operation for emerged weeds and before using pre-emergence herbicides. Add non-ionic surfactant 0.25% v/v. **Paraquat product labels require applicators to take an EPA-approved training every 3 years to mix, load, and apply paraquat.**
3.2 to 6.4 oz League	0.15 to 0.3 imazosulfuron	For non-selective control of broadleaf weeds, grass suppression and yellow nutsedge. Can be applied pre-emergence, post-emergence, or in sequential application.
1.5 to 2.5 lb Lorox 50 DF	0.75 to 1.25 linuron	For control of annual grasses and broadleaf weeds. Apply after planting but before crop emerges. Plant seed at least 2 inches deep. Best results if rainfall or irrigation is applied within 2 weeks of application.

(continued on next page)

WEED CONTROL: Potato *(continued)*

Product Amt/A	lb A.I./A	Comments
1 to 1.5 oz Matrix 25 WSG	0.016 to 0.023 rimsulfuron	For pre-emergence control of broadleaves and grasses. Apply immediately after hilling, drag-off, or reservoir tillage. 1⁄3 to 1 inch rainfall or irrigation is needed for activation. Do not use on potato grown for seed. Matrix can also be applied chemigation. See label for details.
14 to 18 fl oz Outlook 6 E	0.6 to 0.8 dimethenamid-p	For pre-emergence control of broadleaves and grasses. Apply after planting or after drag-off or as chemigation. Leave a 35 foot untreated buffer and avoid applying near endangered plant populations in and around the following counties: Barren, Boone, Hardin, Laurel, Rockcastle, Wolfe. PHI = 40 days.
0.5 to 2.5 pt Poast	0.09 to 0.48 sethoxydim	For control of actively growing grasses only. Use high rate on Johnson grass. PHI = 30 days. Max. rate of 2.5 pt/application and 5 pt/season.
1.5 to 3.0 pt Prowl H2O	0.71 to 1.43 pendimethalin	For control of annual grasses and broadleaf weeds. Can be applied pre-emergence after planting or after drag-off. Can be applied early post-emergence to plants up to 6 inches tall only if plants are not under stress from cold/wet or hot/dry conditions.
16 to 22 fl oz Roundup WeatherMax 5.5L	0.69 to 0.94 glyphosate-salt	For non-selective post-emergence control of annual and perennial grasses and broadleaf weeds. Use only AMS 1 to 2% v/v. Adding a non-ionic surfactant can reduce weed control effectiveness. Min. 30 days before planting any non-labeled crop.
9 to 32 fl oz Select Max	0.07 to 0.24 clethodim	For selective post-emergence control of annual grasses and suppression of perennial grasses. Add crop oil 1% v/v or 1 to 2 qt/A liquid fertilizer or AMS to enhance control of difficult grasses. PHI = 30 days.
0.3 to 1.3 lb TriCor 75 DF	0.2 to 1 metribuzin	For control of annual grasses and broadleaf weeds. Apply pre-emergence broadcast after planting. Do not incorporate. Can be used post-emergence (0.3 to 0.6 lb/A) or as a split-application not to exceed 1.3 lb/A per season on white-skinned varieties (except Atlantic, Chip Belle, Bel Chip, and Shepody) that are not early maturing. Do not use on early maturing or red-skinned varieties. PHI = 60 days.
1.25 to 2 pt Treflan HFP 4 E	0.62 to 1 trifluralin	For pre-emergence control of annual grasses and broadleaf weeds. Apply and incorporate after planting but before emergence, following drag-off, or after potato plants have fully emerged.
2.3 fl oz Weedone LV4 3.84 EC	0.07 2,4-D	For selective post-emergence control of broadleaf weeds. This is a low volatility formulation of 2,4-D. Still, caution should be exercised near sensitive crops such as tomato and grape. For use on fresh market red potatoes only. Crop response depends on variety. Apply in 5 to 25 gal water/A to plants in the pre-bud stage (about 7 to 10 inches high) and a second application about 10 to 14 days later.
Pre-Harvest Vine Killing		
10 lb Copper Sulfate Crystal	10 copper sulfate	To enhance vine-kill, use in 10 to 100 gal water. Can be mixed with diquat to enhance vine kill.
3.2 qt Defol 750	6 sodium chlorate	To defoliate plants, apply 10 days before harvest in 10 to 20 gal water/A. Do not apply under conditions of extreme heat during the middle of the day.
1 to 2 pt Reglone	0.25 to 0.5 diquat	For non-selective contact kill of grasses and broadleaf weeds and top-kill of perennial weeds. Apply to mature potato vines as a pre-harvest desiccation treatment in 20 gal water/A. Make a second application within 5 days if necessary. Include non-ionic surfactant 0.25% v/v. PHI = 7 days.
21 fl oz Rely 280	0.27 glufosinate	Do not use on potatoes grown for seed. Max. 1 application/season. PHI = 9 days.

DISEASE CONTROL: Potatoes

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Black leg, Seed-piece Rots, Tuber-borne Diseases					
Streptomycin[4]	25	n/a	8 oz/100 gal	1 app	Seed piece treatment.
Elumin	22	n/a	8 oz	2 apps	Pink rot and Pythium leak. In furrow banded spray at seeding followed by side dress.
Dithane M45 and mancozeb[5] generics	M	14	1.25 lb per 50 gal water		Seed-piece treatment. There are multiple Dithane formulations and mancozeb generics on the market. See label for use and rates.
Maxim MZ	12/M	14	0.5 lb/cwt	1 app	Seed piece treatment.
MetaStar and metalaxyl[5] generics	4	14	4 to 8 pts		Pink rot and Pythium leak. Preplant and surface application.

(continued on next page)

DISEASE CONTROL: Potatoes *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Orondis Gold	49/4	14	27.8 oz	1 app	For pink rot and Pythium leak. In open furrow application.
Ridomil Gold SL and mefenoxam[5] generics	4	14	.42 fl oz per 1000 row ft		Pink rot and Pythium leak. In furrow and foliar application. Also manages storage rots if applied aerially at flowering.
Black Scurf, Rhizoctonia Stem Canker					
Blocker Flowable, Blocker 4F	14	0	5.2 to 10.4 fl oz[4]	1 app	Use as an in-furrow spray at planting. Rate is dependent on row spacing; see label for directions.
Elatus	11/7	14	0.34 to 0.5 oz/ 1,000 linear ft	1 app	In-furrow spray at planting.
Headline and pyraclostrobin[5] generics	11	3	0.4 to 0.8 fl oz[4]		Rhizoctonia diseases. In-furrow.
Moncut 70 DF	7	0	0.7 to 1.1 lb	1 app	In-furrow application.
Quadris and azoxystrobin[5] generics	11	14	0.4 to 0.8 fl oz per 1000 ft row	1 app	In-furrow or post-emergence. There are multiple Quadris formulations and azoxystrobin generics on the market. See label for rates.
Vertisan	7	7	0.7 to 1.6 fl oz[4]	1 app	Rhizoctonia diseases. In-furrow.
Early Blight, Late Blight, White Mold (Sclerotinia Blight)					
Aftershock and fluoxastrobin[5] generics	11	7	2 to 3.8 fl oz	22.8 fl oz	
Ariston	M/27	14	2.0 pt	17.5 pt	
Bravo and chlorothalonil[4] generics	M	7/14			Early/late blight. There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Cabrio Plus	11/M	14	2 to 2.9 lb	17.4 lb	
Copper, fixed coppers	M	0			Early/late blight. See label for mixing instructions and tank-mix precautions.
Curzate 60 DF	27	14	3.2 oz	7 apps	Late blight only. Must be tank-mixed with a fungicide from FRAC Group M.
Dexter Max	M/11	14	1.6 to 2.1 lb	16 lb	
Dithane M45 and mancozeb[5] generics	M	14	0.5 to 2 lb	14 lb	Early/late blight. There are multiple Dithane formulations and mancozeb generics on the market. See label for rates.
Elumin	22				
Endura and boscalid[4] generics	7	30	2.5 to 10 oz	20.5 oz or 4 apps	Early blight and white mold.
Flint Extra	11	7	3 to 3.8 oz	23 oz	Early and late blight. Tank mix with a protectant fungicide for late blight.
Omega 500 and fluazinam[5] generics	29	14	5.5 to 8 fl oz	56 fl oz	Late blight, white mold.
Forum SC	40	4	4 to 6 fl oz	30 fl oz	Late blight. Must be tank-mixed with another product labeled for late blight.
Gavel 75 DF2	22/M	14	1.5 to 2 lb	6 apps	Early/late blight.
Gem	11	7	6 to 8 oz	6 apps	Early/late blight.
Headline and pyraclostrobin[5] generics	11	3	6 to 12 fl oz[6]	6 apps	
Luna Tranquility	7/9	7	11.2 fl oz	33.6 fl oz	Early blight, white mold.
ManKocide[3]	M	14	1.5 to 5 lb	see footnote	Early/late blight.
Miravis Prime	7/12	14	9.2 to 11.4 oz	34.2 oz	Early blight and white mold.
Orondis Opti	49/M	7	1.75 to 2.5 pt	10 pt	Do not use with any other Orondis product.
Orondis Ultra	49/40	14	5.5 to 8.0 oz	32 oz	Late blight. Do not use with any other Orondis product.
Presidio	43	7	4 fl oz	12 fl oz	Late blight.
Previcur Flex	28	14	0.7 to 1.2 pt	6 pt	Early/late blight.

(continued on next page)

DISEASE CONTROL: Potatoes *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Priaxor	7/11	7	4 to 8 fl oz	24 fl oz	
Provysol	3	7	3 to 5 oz	15 oz	Foliar fungal diseases.
Quadris and azoxystrobin[5] generics	11	14	6 to 15.5 fl oz	120 fl oz	Early/late blight. There are multiple Quadris formulations and azoxystrobin generics on the market. See label for rates.
Quadris Opti	11/M	14	1.6 pt	6 apps	Early blight/late blight.
Quadris Top	11/3	14	8 to 14 fl oz	55.3 fl oz	Early blight.
Quash	3	1	2.5 to 4 oz	4 apps	Early blight, white mold.
Ranman SC	21	7	1.4 to 2.75 fl oz	10 apps	Late blight.
Reason	11	14	5.5 to 8.2 fl oz	24.6 fl oz	Early blight/late blight.
Revus	40	14	5.5 to 8 fl oz	32 fl oz	Late blight only. Use a spreader/penetrant surfactant. Must be tank-mixed with a fungicide NOT in FRAC Group 40.
Revus Top	40/3	14	5.5 to 7 fl oz	28 fl oz	Early/late blight only. Use a spreader/penetrant surfactant.
Ridomil Gold Bravo SC	4/M	14	2.5 pt	3 apps	Early/late blight.
Ridomil Gold Copper	4/M	14	2 lb		Late blight.
Ridomil Gold MZ2	4/M	14	2.5 lb		Early/late blight.
Rovral and iprodione[5] generics	2	14	1 to 2 pt	4 apps	Early blight and white mold.
Scala	9	7	7 fl oz	35 fl oz	Early blight. Tank-mix with another fungicide labeled for early blight.
Tanos	11/27	14	6 to 8 oz	6 apps	Early/late blight. Tanos must be tank-mixed with a fungicide from FRAC Group M appropriate for the target disease.
Topsin M and thiophanate-methyl[5] generics	1	21	1 to 1.5 lb	4 lbs	White mold. Apply before row closure.
Velum Prime	7	7	6.5 fl oz	13.7 fl oz	Early blight and white mold, also nematodes. Apply as an in-furrow spray.
Vertisan	7	7	10 to 24 fl oz	72 fl oz	Early blight and white mold.
Zampro	40/45	4	11 to 14 fl oz	3 apps	
Zing!	M/22	7	32 to 34 fl oz	8 apps	

1 Products with numerical FRAC codes must be alternated or tank-mixed with products that have a different FRAC code to discourage resistance development. See product label for maximum number of consecutive applications allowed. Refer to the table on pages 22-24 for more information on FRAC codes.
2 Pre-harvest interval.
3 Observe seasonal limits for mancozeb.
4 Per 1,000 row-feet.
5 Generic products available (Appendix F). Amounts and seasonal limits per acre are product dependent.
6 Use higher rate when pressure is severe.

Root Crops

(Beets, Carrots, Parsnips, Radishes, Turnips)

Planting and Culture

Plant in rows 18 to 24 inches apart and ½ inch deep. Seed 8 to 10 pounds per acre for bunching. Seed will germinate between 40° and 85°F. Optimum temperature is 65° to 75°F. Color and quality are best when the plant develops during cool temperatures (50° to 60°F, see Appendix K). The sugar content of beets will be lower when grown in warm weather, and they will have a lighter color. Hot weather produces white bands in the roots. Beets are sensitive to soil acidity and should be grown at a pH between 6.2 and 7.0.

Plant in rows 18 to 24 inches apart and ¼ to ½ inch deep. Seed 2 to 4 pounds per acre. Seed are often variable in germination and emergence, resulting in non-uniform stands. Seed germinate slowly, and it is necessary to maintain adequate moisture. Select deep, sandy loam soils for best results. Carrots generally are misshapen when grown on heavy or rocky soils. Prepare soil deeply. Use low raised beds.

Plant in rows 18 to 24 inches apart and ¼ to ½ inch deep. Seed 2 to 3 pounds per acre. Prepare soil similarly to that for carrots. Always use new seed, because germination of seed 1 year or older is poor.

Plant seed in rows 15 inches apart and ¼ to ½ inch deep. Plant 12 to 15 seed per foot of row. Seed 10 to 15 pounds per acre. Seed germinate in three to four days at a soil temperature of 65°F or above. Best quality and shape of roots are attained when the crop grows and matures at 50° to 65°F.

Plant seed in rows 14 to 18 inches apart with seed 2 to 3 inches apart in the rows and ¼ to ½ inch deep. Plant 1 to 2 pounds of seed per acre. Best quality and yields are obtained under moderately cool temperatures. See also the "Greens" chapter.

Fertilizing

The soil pH should be between 6.0 and 6.8. Boron may become a limiting element for root crops. Apply Borax at the rate of 20 pounds per acre (2 pounds actual Boron) if necessary as indicated by soil test results.

Carrots tend to develop forked roots on heavy or rocky soils.

Harvesting

All root crops should be harvested when mature but before they become woody and tough. Wash roots carefully and package according to market requirements. Store at 32°F and 90 to 95 percent relative humidity.

VARIETIES: Root Crops

Variety	DTM[1]	Comments
BEETS[2]		
Avalanche	45	White color, sweet flavor; intermediate resistance to Cercospora leaf spot
Boro	51	Dark red, excellent flavor, widely adapted; tops are resistant to foliar blights
Red Ace (hybrid)	53	Early maturing, attractive, very smooth skin, excellent quality roots and greens, very sweet, heat resistant.
Kestrel (hybrid)	53	Excellent appearance and taste of cooked and raw roots and cooked greens, uniform size and shape, very sweet.
Red Cloud (hybrid)	53	Excellent appearance and sweet taste raw, good roasted taste, excellent cooked greens.
Merlin (hybrid)	55	Excellent appearance and taste of cooked and raw roots and cooked greens, uniform size and shape, lower Cercospora leaf spot incidence.
Chioggia Guardsmark	60	Attractive red and white zoned interior.
Ruby Queen	60	Attractive, excellent quality, very sweet, excellent for processing.
Touchstone Gold	60	Specialty gold fleshed beet, excellent flavor, lower germination percentage, low Cercospora leaf spot incidence.
Taunus	65	Very uniform smooth skinned, attractive long cylindrical beet for slicing, excellent flavor cooked, easy cleaning, low Cercospora leaf spot incidence.
CARROTS[3]		
Napoli	33	Nantes type, slightly tapered, 7 inch carrots
Mokum	54	Early, Nantes type, slender with slight taper, 6 inch carrots
Sugarsnax (hybrid)	68	Mid-season, Imperator hybrid, with a deep orange interior.
Purple Haze	73	Purple exterior, orange interior, Imperator hybrid good for markets, AAS winner.
PARSNIPS[4]		
Lancer (hybrid)	110	Slim, smooth roots, high quality (for trial).
Harris Model	120	Smooth, white roots.
RADISHES[5]		
Small round types		
Cherry Belle	24	Open-pollinated; popular variety
Roxanne	24	Good heat resistance, less pithiness when large; uniform roots

(continued on next page)

VARIETIES: Root Crops *(continued)*

Variety	DTM[1]	Comments
Crunchy Royale	25	Bright red, uniform, works best under cool conditions
Cook's Custom Blend	27	Mixture of four root colors and different shapes
Pink Beauty	29	Uniform roots, medium tops, resists pithiness
Sparkler	30	Two-tone round root, mild taste
Oriental Radishes		
Minowase Summer Cross	50	Long white daikon, mild flavor, juicy and tender, *Fusarium* resistant, stands heat, fall crop.
April Cross	60	Long white daikon, slow to bolt.
Misato Rose	60	Round, 4 inches in diameter, white with light green shoulders and a dark pink interior; very tender, pungent skin, mild and sweet interior, excellent for eating fresh, garnishing, and pickling. Fall production only, plant in August or September.
Tae Baek	70	Korean radish, short white barrel-shaped roots with a green shoulder, somewhat pungent, for heavier soils, highly disease tolerant, fall crop.
TURNIPS[6]		
Hakurei (hybrid)	38	Early, all white, best harvested young (2 inch diameter).
Royal Crown (hybrid)	45-50	Purple top, attractive roots and tops.
Just Right	50-70	All white roots, moderate turnip flavor, excellent tasting greens.

1 Days to Maturity
2 (Chenopodiaceae) goosefoot family: Beta vulgaris Crassa group.
3 (Apiaceae) carrot family: Daucus carota var. sativa.
4 Pastinaca sativa.
5 (Brassicaceae) mustard family: Raphanus sativus.
6 Brassica rapa Rapifera group.

FERTILIZER: Root Crops

Soil Test Results (lb/A)		Fertilizer Needed (lb/A)
Phosphorus		**Phosphate (P_2O_5)**
Low	<31	121-180
Medium	31-60	61-120
High	61-80	1-60
Very High	>80	0
Potassium		**Potash (K_2O)**
Low	<201	101-150
Medium	201-300	51-100
High	301-450	1-50
Very High	>450	0
Nitrogen		**N**

Apply 50 lb of actual nitrogen (N)/A. Broadcast all fertilizer and disk into soil thoroughly before seeding.

PESTICIDE SAFETY: Root Crops

	Signal[1]	Re-entry (hrs)	Harvest (days)
FUNGICIDES			
Beets			
Azoxystrobin[2]	C	12	0
Cabrio EG	C	12	0
Fixed coppers[2]	D	12/24	1
Fontelis	C	12	0
Luna Sensation	C	12	7
Luna Tranquility	C	12	7
Metalaxyl[2]	W	48	0
Merivon	W	12	7
Miravis Prime	C	12	7
Presidio	C	12	7
Pristine	C	12	0

(continued)

PESTICIDE SAFETY: Root Crops *(continued)*

	Signal[1]	Re-entry (hrs)	Harvest (days)
Propiconazole[2]	W	12	14
Quadris	C	4	0
Ridomil Gold SL	C	48	0
Reason 500 SC	C	12	14
Sulfur[2]	C	24	0
Switch 62.5WG	C	12	7
Tebuconazole[2]	C	12	7
Trifloxystrobin[2]	C	12	7
Uniform	C	0	-
Carrots			
Azoxystrobin[2]	C	4	0
Azoxystrobin + Propiconazole	W	12	14
Cabrio EG	C	12	0
Chlorothalonil[2]	D	12	0
Endura	W	12	0
Fixed coppers[2]	D	12/24	0
Flint Extra	C	12	7
Fluazinam[2]	W	48	7
Fontelis	C	12	0
Inspire Super	C	12	7
Iprodione[2]	C	24	0
Luna Sensation	C	12	7
Luna Tranquility	C	12	7
Merivon	W	12	7
Mefenoxam[2]	C	48	0
Metalaxyl[2]	W	48	0
Miravis Prime	C	12	7
Presidio	C	12	7

(continued on the next page)

PESTICIDE SAFETY: Root Crops *(continued)*

	Signal[1]	Re-entry (hrs)	Harvest (days)
Pristine	C	12	0
Propiconazole[2]	W	12	14
Quadris Opti	W	12	0
Quadris Top	C	12	7
Ranman	C	12	14
Reason 500 SC	C	12	14
Ridomil Gold Bravo SC	W	48	7
Ridomil Gold Copper	D	48	7
Sulfur[2]	C	24	0
Switch 62.5WG	C	12	7
Tebuconazole[2]	C	12	7
Trifloxystrobin[2]	C	12	7
Parsnips			
Azoxystrobin[2]	C	4	0
Cabrio EG	C	12	0
Chlorothalonil[2]	D	12	10
Fontelis	C	12	0
Luna Sensation	C	12	7
Luna Tranquility	C	12	7
Merivon	W	12	7
Mefenoxam[2]	C	48	0
Metalaxyl[2]	W	48	0
Miravis Prime	C	12	7
Presidio	C	12	7

(continued)

PESTICIDE SAFETY: Root Crops *(continued)*

	Signal[1]	Re-entry (hrs)	Harvest (days)
Pristine	C	12	0
Reason 500 SC	C	12	14
Switch 62.5WG	C	12	7
Trifloxystrobin[2]	C	12	7
Uniform	C	0	-
Radish			
Azoxystrobin[2]	C	4	0
Cabrio EG	C	12	0
Fontelis	C	12	0
Luna Sensation	C	12	7
Luna Tranquility	C	12	7
Merivon	W	12	7
Mefenoxam[2]	C	48	0
Metalaxyl[2]	W	48	0
Miravis Prime	C	12	7
Presidio	C	12	7
Pristine	C	12	0
Quilt	W	12	14
Reason 500 SC	C	12	14
Ridomil Gold Copper	D	48	7
Switch 62.5WG	C	12	7
Trifloxystrobin[2]	C	12	7
Uniform	C	0	-

1 W: Warning, C: Caution, D: Danger; P: Poison
2 Several formulations are marketed. See the general introduction for more details on fungicides.

PESTICIDE SAFETY: Root Crops

	Signal[1]	Re-entry (hrs)	Harvest (days)				
			Beets	Carrots	Parsnips	Radishes	Turnips
INSECTICIDES							
Actara 25 WDG	C	12	7	7	7	7	7
Admire Pro	C	12	7/21[2]	7/21[2]	7/21[2]	7/21[2]	7/21[2]
Beleaf 50 SG	C	12	3	3	3	3	3
Blackhawk 36 WG	C	4	3	3	3	3	3
Coragen 1.67 SC	-	4	1	1	1	1	1
Exirel 0.83 SE	C	12	1	1	1	1	1
Intrepid 2 F	C	12	1	1	1	1	1
Knack 0.83 EC	C	12	3	3	3	3	3
Malathion 8	C	12	7	7	7	7	-
Movento 2 SC	C	24	-	7	-	-	-
Platinum 2 SC	C	12	AP	AP	AP	AP	AP
Radiant SC	C	4	7	3	3	3	3
Requiem EC	C	4	0	0	0	0	0
Sevin XLR Plus	W	12	7	7	7	7	7
Sivanto Prime 1.67 SL	C	12	7	7	7	7	7
Transform 50 WG	DP	24	7	7	7	7	7
Vantacor 5 SC	-	4	1	1	1	1	1
Verimark 1.67 SL	-	4	AP	AP	AP	AP	AP
Restricted Use							
Asana XL	W	12	-	7	-	7	-
Baythroid XL	W	12	0	0	0	0	0
Brigade 2 EC	W	12	1	21	21	21	21
Diazinon AG500	C	24	14	14	-	14	-

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PESTICIDE SAFETY: Root Crops *(continued)*

	Signal[1]	Re-entry (hrs)	Harvest (days)				
			Beets	Carrots	Parsnips	Radishes	Turnips
Diazinon 50 W	C	24	3	3	-	3	-
Fastac 0.83 EC	D	12	1	1	1	1	1
Lannate 90 SP	DP	48	0/10[2]	1	-	-	-
Mustang Maxx	W	12	1	1	1	1	1

- Indicates crop does not appear on label.
1 W: Warning, C: Caution, D: Danger; P: Poison.
2 PHI depends on the method of application.

INSECT CONTROL: Root Crops[1]

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
Aphids			
Actara 25 WDG	1.5 to 3 oz	8 oz	Allow 7 days between applications.
Admire Pro	1.2 fl oz	1.2 or 3.7 fl oz	Allow 5 days between applications.
Beleaf 50 SG	2 to 2.8 oz	8.4 oz	Allow 7 days between applications.
Exirel 0.83 SC	13.5 to 20.5 fl oz	61.5 fl oz	Allow 5 days between applications.
Malathion 8	1.25 pt	3 applications	Allow 7 days between applications.
Movento 2 SC	5 fl oz	10 fl oz	Allow 7 days between applications.
Tranform 50 WG	0.75 to 1.5 oz	8.5 oz	Allow 7 days between applications.
Sivanto Prime 1.67 SL	7 to 14 fl oz	28 fl oz	Allow 10 days between applications.
Armyworms			
Coragen 1.67 SC	3.5 to 7.5 fl oz	15.4 fl oz	Allow 3 days between applications.
Fastac 0.83 EC	3.2 to 3.8 fl oz	11.4 fl oz	Allow 4 days between applications.
Intrepid 2 F	8 to 16 fl oz	64 fl oz	Allow 14 days between applicatons.
Lannate 90 SP	0.5 to 1 lb	4 or 7 lb	-
Radiant SC	5 to 10 fl oz	34 fl oz	Allow 4 days between applications.
Cutworms			
Asana XL	5.8 to 9.6 fl oz	96 fl oz	-
Baythroid XL	1.6 to 2.8 fl oz	14 fl oz	Allow 7 days between applications.
Brigade 2 EC	5.12 to 6.4 fl oz	25.6 fl oz	Allow 7 days between applications.
Mustang Maxx	1.24 to 4 fl oz	24 fl oz	Allow 4 days between applications.
Flea Beetles			
Actara 25 WDG	1.5 to 3 oz	8 oz	Allow 7 days between applications.
Admire Pro	1.2 fl oz	1.2 or 3.7 fl oz	Allow 5 days between applications.
Asana XL	5.8 to 9.6 fl oz	96 fl oz	Radishes only.
Baythroid XL	1.6 to 2.8 fl oz	14 fl oz	Allow 7 days between applications.
Blackhawk 36WG	1.7 to 3.3 oz	14.4 oz	Allow 7 days between applications.
Brigade 2 EC	5.12 to 6.4 fl oz	25.6 fl oz	Allow 7 days between applications.
Exirel 0.83 SC	13.5 to 26.5 fl oz	61.5 fl oz	Allow 5 days between applications.
Fastac 0.83 EC	1.8 to 3.8 fl oz	11.4 fl oz	Allow 4 days between applications.
Mustang Maxx	1.76 to 4 fl oz	24 fl oz	Allow 4 days between applications.
Sevin XLR Plus	0.5 to 1 qt	6 qt	Limit 6 applications. Allow 7 days between sprays.
Leafhoppers: Treat fields and field margins to control these disease vectors. Beginning when plants are 3 inches tall.			
Actara 25 WDG	1.5 to 3 oz	8 oz	Allow 7 days between applications.
Admire Pro	1.2 fl oz	1.2 or 3.7 fl oz	Allow 5 days between applications.
Baythroid XL	1.6 to 2.8 fl oz	14 fl oz	-
Fastac 0.83 EC	1.8 to 3.8 fl oz	11.4 fl oz	Allow 4 days between applications.
Lannate 90 SP	0.5 to 1 lb	4 or 7 lb	-
Mustang Maxx	1.76 to 4 fl oz	24 fl oz	Allow 4 days between applications.
Sevin XLR Plus	0.5 to 2 qt	6 qt	Allow 7 days between sprays. Limit 6 qt/A.
Sivanto Prime 1.67 SL	7 to 14 fl oz	28 fl oz	Allow 10 days between applications.
Transform 50 WG	1.5 to 2.25 oz	8.5 oz	Allow 7 days between applications.
Plant Bugs			
Mustang Maxx	3.2 to 4 fl oz	24 fl oz	Allow 4 days between applications.
Sevin XLR Plus	1 to 2 qt	6 qt	Limit 6 applications. Allow 7 days between sprays.
Crickets, Sowbugs			
Baythroid XL	1.6 to 2.8 fl oz	14 fl oz	Allow 7 days between applications.

1 Generic products available (Appendix G).

WEED CONTROL: Root Crops

Product Amt/A	Lb A.I./A	Comments
0.5 to 1.6 fl oz Aim 1.9 EW	0.008 to 0.025 carfentrazone	For contact post-emergence control of annual broadleaf weeds and suppression of annual grasses. Can be applied as a preplant, pre-transplant burndown, or before crop emerges to actively growing weeds up to 4 inches tall. Can also be applied post-emergence as a directed hooded application between crop rows. Use min. 10 gal water/A and crop oil 1% v/v. Max. rate 6.1 fl oz/A. PHI = 0 days.
2 to 4 pt Caparol 4L	1 to 2 prometryn	Carrot only. Can be applied pre-emergence and or post-emergence over the top. Apply up to three applications of at the rate of 2 to 4 pt/A per application. Apply one pre-emergence at 2 to 4 pt/A. Make one post-emergence application at up to 4 pt/A or two post-emergence applications each at a maximum of 2 pt/A. Make post-emergence applications through the 6 leaf stage of carrot development in a minimum of 20 gallons of water per acre. When applying to emerged weeds add 2 qt of a nonionic surfactant (NIS) to 100 gal of spray mixture (0.5%) v/v. Restrictions: (1) Do not apply within 30 days of harvest. (2) Do not exceed 8 pt/A of Caparol 4L Herbicide per crop cycle. (3) Do not make more than 3 applications per crop cycle.
6 to 14 lb Dacthal W-75	4.5 to 10.5 DCPA	Radish only. For pre-emergence control of annual grasses and small-seeded broadleaves. For radish apply at seeding or up to 3-leaf stage. Soil should be clean-cultivated before application. Apply in 20 to 30 gal water/A. PHI = 25 days.
1 pt Fusilade-DX 2E	0.25 fluazifop-p	Carrot only. For selective post-emergence control of annual grasses and suppression of perennial grasses. Include 1% v/v crop oil or 0.25% v/v non-ionic surfactant/A. PHI = 45 days. Max. rate is 48 fl oz/A.
2 to 4 pt Gramoxone Inteon	0.67 to 1.35 paraquat salt	Carrot only. For non-selective contact kill of annual grasses and broadleaf weeds and top-kill of perennial weeds. Apply preplant, pre-emergence, or before transplanting in min. 10 gal water/A. Apply banded or broadcast. Use higher rate for heavy weed infestations. Use non-ionic surfactant 0.25% v/v. **Paraquat product labels require applicators to take an EPA-approved training every 3 years to mix, load, and apply paraquat.**
1.5 to 3 lb Lorox 50 DF	0.75 to 1.5 linuron	Carrot and parsnip only. For control of annual grasses and broadleaf weeds. Apply post-emergence as a non-directed spray to carrots > 3 inches tall. Apply before annual grasses exceed 2 inches high and before broadleaves exceed 6 inches high. Check label regarding varietal tolerance. Do not apply when temperature is above 85°F. PHI = 14 days.
0.5 to 2.5 pt Poast	0.09 to 0.49 sethoxydim	For control of actively growing grasses only. Use high rate on Johnson grass. PHI = 60 days. Max. rate of 2.5 pt/application and 5 pt/season.
2.0 pt Prowl H2O	0.95 pendimethalin	Carrot only. For pre-emergent control of most annual grasses and some broadleaf weeds. Apply as a broadcast application as a post plant treatment prior to crop and weed emergence. May be applied at layby at 2.0 pt/A as a directed spray between rows. Do not allow to come in contact with plants or severe injury will result. PHI = 60 days.
16 to 22 fl oz Roundup WeatherMax 5.5L	0.69 to 0.94 glyphosate-salt	For non-selective post-emergence control of annual and perennial grasses and broadleaf weeds. Use only AMS 1 to 2% v/v. Adding a non-ionic surfactant can reduce weed control effectiveness. Min. 30 days before planting any non-labeled crop.
3 to 10% v/v Scythe	0.13-0.39 pelargonic acid	For non-selective post-emergence control of annual and perennial grasses and broadleaf weeds. Beet, carrot, parsnip, radish, turnip.
9 to 16 fl oz Select Max	0.07 to 0.12 clethodim	For selective post-emergence of actively growing annual grasses and suppression of perennial grasses. Add crop oil 1% v/v. Max. 16 fl oz/ application. Min. 14 days between applications. PHI = 30 days.
1.25 to 2 pt Treflan HFP 4 E	0.6 to 1 trifluralin	Carrot and radish only. For control of annual grasses and broadleaf weeds. Apply and incorporate in spring before planting.
0.3 lb TriCor 75 DF	0.2 metribuzin	Carrot only. For control of annual grasses and broadleaf weeds. Apply broadcast over the tops to plants with 5 to 6 true leaves but before weeds are 1 inch tall. A second application can be made 3 weeks later. Do not apply within 3 days of stress conditions such as cool, wet and cloudy weather or hot days or after any other chemical to avoid injury. PHI = 60 days.

DISEASE CONTROL: Root Crops

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
BEETS, RADISH, TURNIPS, PARSNIPS					
Damping-off (Pythium)					
MetaStar and metalaxyl[3] generics	4	0	4 to 8 pt	1 app	Preplant or at planting. May be applied through drip irrigation. Will control white rust on radish.
Presidio	43	7	3 to 4 fl oz	12 fl oz	May be applied through drip irrigation at planting.
Reason 500 SC	11	14	5.5 to 8.2 fl oz	24.6 fl oz	Not for radish. Suppression only.
Ridomil gold and mefenoxam[3] generics	4	0	1 to 2 pt	2 pt	Preplant and at planting. May be applied through drip irritation.
Downy Mildew					
Bravo and chlorothalonil[3] generics	M	0			Parsnip. There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Copper, fixed coppers[3]	M	0			Beets. See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Leaf Spots (*Alternaria*, Anthracnose, *Cercospora*), Rust, White Rust					
Bravo and chlorothalonil[3] generics	M	0			Parsnip. There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Cabrio and pyraclostrobin[3] generics	11	0	8 to 16 oz	3 apps	
Copper, fixed coppers[3]	M	0			Cercospora leaf spot on beets. See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Endura and boscalid[3] generics	7	0	4.5 to 7.8 oz	23.4 oz	
Flint Extra	11	0	2.0 to 4.0 oz	8 to 12 oz	Lower seasonal limit for radishes.
Fontelis	7	0	16 to 30 fl oz	61 fl oz	
Gem 500SC	11	7	1.9 to 2.9 fl oz	4 apps	
Luna Sensation	7/11	7	4.0 to 7.6 fl oz	23 fl oz	
Luna Tranquility	7/9	7	11.2 fl oz	54.7 fl oz	
Merivon	7/11	7	4 to 5.5 fl oz	3 apps	
Miravis Prime	7/12	7	6.8 oz	20.4 oz	
Pristine	7/11	0	8 to 10.5 oz	63 oz	
Quadris and azoxystrobin[3] generics	11	0	6 to 15.5 fl oz	120 fl oz	There are multiple Quadris formulations and azoxystrobin generics on the market. See label for rates and application detail.
Quilt	3/11	7	10.5 to 14 fl oz	55 fl oz	Cercospora leaf spot on radish only.
Reason 500 SC	11	14	8.2 fl oz	24.6 fl oz	Alternaria leaf blight. Not for radish.
Ridomil Gold Copper	4/M	0	2 lb	4 apps	White rust on radish. See label for rates and rotation instructions.
Sulfur[3]	M				Beets. Phytotoxicity may occur when sulfur is applied when temperatures exceed 90°F.
Switch 62.5WG	9/12	7	11 to 14 oz	56 oz	For Alternaria leaf blight, apply every 7 to 10 days. Make only two applications on radish.
Tilt and propiconazole[3] generics	3	7	3 to 4 fl oz	16 fl oz	
CARROTS					
Damping-off, Seed Rot, Root Rots, Southern Blight					
MetaStar and metalaxyl[3] generics	4	0	4 to 8 pt	1 app	Preplant or at planting. May be applied through drip irrigation.
Presidio	43	7	4 fl oz	12 fl oz	*Pythium* diseases. Can be applied in-furrow or side-dressed after emergence.

(continued on next page)

DISEASE CONTROL: Root Crops *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Quadris and azoxystrobin[3] generics	11	0			There are multiple Quadris formulations and azoxystrobin generics on the market. See label for rates and application detail.
Reason 500 SC	11	14	8.2 fl oz	24.6 fl oz	Cavity spot (*Pythium*). Do not use a spreader/ sticker. Alternate with mefenoxam.
Ridomil Gold SL and mefenoxam[3] generics	4	7	4 to 8 pt	1 app	*Pythium* diseases. May be applied through drip irrigation.
Ridomil Gold Bravo SC	4/M	7	1.5 to 2.5 pt	4 apps	*Pythium* diseases. See label for rates and rotation detail.
Ridomil Gold Copper	4/M	7	2 lb		*Pythium* diseases.
Foliar Diseases (Alternaria, Cercospora Leaf Spots, Leaf Blights)					
Bravo and chlorothalonil[3] generics	M	0			There are multiple Bravo formulations and chlorothalonil generics on the market. See label for rates.
Cabrio and pyraclostrobin[3] generics	11	0	8 to 12 oz	3 apps	
Copper, fixed coppers[3]	M	0			See label for rates, mixing instructions, and tank-mix precautions. Some products are approved for greenhouse use.
Endura and boscalid generics	7	0	4.5 oz	5 apps	Alternaria leaf blight.
Flint Extra	11	7	2.0 to 2.9 oz	11.5 oz	
Fontelis	7	0	16 to 30 fl oz	61 fl oz	
Inspire Super	3/9	7	16 to 20 oz	80 oz	
Luna Sensation	7/11	7	4.0 to 7.6 fl oz	23 fl oz	
Luna Tranquility	7/9	7	11.2 fl oz	54.7 fl oz	
Merivon	7/11	7	4 to 5.5 fl oz	3 apps	
Miravis Prime	7/12	7	6.8 oz	20.4 oz	
Omega 500 and fluazinam[3] generics	29	7	16 fl oz	4 apps	
Pristine	7/11	0	8 to 10.5 oz	6 apps	Will suppress southern blight.
Rovral and iprodione[3] generics	2	0	1 pt	10 pts	Alternaria blight.
Tilt and propiconazole[3] generics	3	14	4 fl oz	16 fl oz	
Quilt Xcel and propiconazole + azoxystrobin[3] generics	3/11	14	14 fl oz	56 fl oz	
Quadris and azoxystrobin[3] generics	11	0	9 to 15.5 fl oz	120 fl oz	There are multiple Quadris formulations and azoxystrobin generics on the market. See label for rates and application detail.
Quadris Opti	11/M	0	2.4 pt	6 apps	
Quadris Top	11/3	7	12 to 14 fl oz	56 fl oz	
Sulfur[3]	M				Phytotoxicity may occur when sulfur is applied when temperatures exceed 90ºF.
Switch 62.5 WG	9/12	7	11 to 14 oz	56 oz	Alternaria leaf blight.

1 Products with numerical FRAC codes must be alternated or tank-mixed with products that have a different FRAC code to discourage resistance development. See product label for maximum number of consecutive applications allowed. Refer to the table on pages 22-24 for more information on FRAC codes.

2 Pre-harvest interval.

3 Generic products available (Appendix F). Amounts and seasonal limits per acre are product dependent.

Sweetpotatoes

Bindweed family (Convolvulaceae): *Ipomoea batatas*

Planting and Culture

Sweetpotatoes grow best on medium to light sandy soils that are well drained and relatively low in nitrogen, although they can be grown successfully on heavier soils. Regardless, sweetpotatoes should not be grown on the same land more often than once every three years.

Good soil preparation is important for successful production of sweetpotatoes. The soil organic matter content should be maintained by turning under small grain cover crops.

The commercial grower often produces his own transplants (slips) by bedding 10 to 12 bushels of sweetpotatoes for each acre of plants to be set. The sweetpotatoes are usually bedded about seven weeks before the field setting date in early June (see Appendix K). Use only disease-free sweetpotatoes. They should be treated to reduce surface-borne disease problems before being placed in the bed. Do not cut sweetpotato seed pieces as you would potatoes. Cutting will often result in disease and will not result in a greater number of slips.

In preparing the bed, the roots are usually placed by hand so they are close together but not touching. Ordinarily, one bushel will cover 16 to 20 square feet of bed surface. The roots should be covered with 3 to 4 inches of sand or fine soil, then watered.

Soil preparation begins with deep plowing and repeated disking until a fine plant bed is prepared. Sandy soil should be ridged about 10 inches high before planting. On heavier soils that do not drain quickly, the ridges should be 12 to 14 inches high.

The best transplanting results are obtained by using freshly pulled plants. True "slips" will have been pulled from the sweetpotato and may have some roots. Often, to reduce risk of soilborne diseases, cuttings of vines are used instead of slips. Cuttings are taken 1 to 2 inches above the soil line and will have no roots when set. Slips may be set by hand, but most commercial Kentucky growers use a one-row tobacco setter that applies about ½ pint of water with each slip. Large commercial growers use a two-row plant setter. A starter solution is preferred to water. Add 3 pounds of 10-52-17 fertilizer to 50 gallons of water and use about ½ pint of this starter solution per slip (plant).

Rows should be spaced 40 to 44 inches apart and plants should be spaced in the row every 10 to 12 inches. A spacing of 10 inches apart within row and 44 inches between rows requires about 13,400 plants to set an acre. Replace missing plants to avoid oversized roots.

Fertilizing

Sweetpotatoes grow well at a soil pH of 5.0 to 6.0. Broadcast all fertilizer and disk into soil well before transplanting.

Harvesting

Sweetpotatoes continue to grow until the vines are killed by frost. Therefore, you should harvest the crop when the greatest number of 8- to 10-ounce potatoes are found in the hill. Sample digging will provide this information. A good practice is to mow the vines before harvesting. The crop can then be harvested with less damage to the potatoes. Use a turn plow or a potato digger to expose the roots with the least possible injury. Plow out one row at a time and pick up the potatoes. Grade potatoes in the field and place them in containers that are to be put in storage. For large-scale production, mechanical harvesting machinery can be used economically.

Curing and Storing

Stack crates or baskets in the storage space. Place them 6 to 8 inches off the floor and 12 to 15 inches from the walls to allow for adequate ventilation. Curing requires seven to 10 days if the temperature can be maintained at 80° to 85°F with 70 to 90 percent relative humidity. After curing is completed, the potatoes should be kept in a place as near 55°F as possible with a relative humidity of 85 percent. Higher market prices occur during the winter months and usually permit the grower with a stored crop to increase profits substantially.

Preparing for Market

If the crop is to be sold, the potatoes should be graded to meet the buyer's requirements. They should be prepared for market by cleaning, either by brushing or washing, and waxing before packing in crates or baskets. A box of sweetpotatoes on the wholesale market often weighs 40 to 44 pounds.

VARIETIES: Sweetpotatoes

Variety	DTM[1]	Comments
Beauregard	90	Copper skin, deep orange flesh, slow to sprout, moist flesh, very high yield, must harvest on time or roots will get too large.
Hernandez	90-100	Bright orange skin, orange moist flesh, long tapered root.
O'Henry	90-100	White skin, cream flesh, uniform shape, very high yield.
Covington	110	Rose colored skin, orange flesh, very uniform and high quality roots, strong vines.
Japanese/ Murasaki	100-105	Purple skin, dry-white flesh, good yields, strong skin, for farmers markets.

1 Days to Maturity

FERTILIZER: Sweetpotatoes

Soil Test Results (lb/A)		Fertilizer Needed (lb/A)
Phosphorus		**Phosphate (P_2O_5)**
Low	<31	121-180
Medium	31-60	61-120
High	61-80	1-60
Very High	>80	0
Potassium		**Potash (K_2O)**
Low	<201	251-275
Medium	201-300	101-250
High	301-450	51-100
Very High	>450	50
Nitrogen		**N**

Apply 30 to 50 lb/A of actual nitrogen (N).

PESTICIDE SAFETY: Sweetpotatoes

	Signal[1]	Re-entry (hrs)	Harvest (days)[2]
INSECTICIDES			
Actara 25 WDG	C	12	14
Admire Pro	C	12	125
Assail 30 SG	C	12	7
Avaunt eVo 30 DG	C	12	14
Belay 21.3 SC	C	12	14
Beleaf 50 SG	C	12	7
Coragen 1.67 SC	-	4	14
Exirel 0.83 SE	C	12	7
Fulfill 50 DF	C	12	14
Harvanta 50 SL	C	4	7
Intrepid 2 F	C	4	7
Knack 0.86 EC	C	12	7
Malathion 8	W	12	3
Miteus 0.42 EC	W	12	7
Movento 2	C	24	7
Nurizma 2.5 SC	C	12	AP
Oberon 2 SC	C	12	7
Platinum 2 F	C	12	AP
PQZ 1.87 SC	C	12	14
Portal XLO 0.4 EC	W	12	7
Radiant SC	C	4	7
Rimon 0.83 EC	W	12	14
Scorpion 35 SL	C	12	7[4]
Sefina 0.42 SC	C	12	7

continued

PESTICIDE SAFETY: Sweetpotatoes *(continued)*

	Signal[1]	Re-entry (hrs)	Harvest (days)[2]
Sevin XLR Plus	W	12	7
Sivanto Prime 1.67 SL	C	12	7
Transform 50 WG	D	24	7
Torac 1.29 EC	W	12	14
Venom 70 SG	C	12	7
Verimark 1.67 SL	-	4	N/A
Restricted Use			
AgriMek 0.7 SC	W	12	14
Baythroid XL	W	12	0
Brigade 2 EC	W	12	21
Exirel 0.83 SE	C	12	7
Fastac 0.83 EC	D	12	1
Mustang Maxx	W	12	1
Vydate L	DP	48	AP
Warrior II	W	24	7
FUNGICIDES			
Aprovia Top	W	12	14
Azoxystrobin[3]	C	4	14
Botran 75 W[4]	C	12	0
Botran 5F[4]	C	12	0
Endura	W	12	10
Fluazinam[2]	W	12	30
Fluoxastrobin[2]	C	12	7
Headline SC	W	12	3
Luna Tranquility	C	12	7

continued

PESTICIDE SAFETY: Sweetpotatoes *(continued)*

	Signal[1]	Re-entry (hrs)	Harvest (days)[2]
Maxim 4 FS	C	0	0
Mertect 340 F	C	12	0
Metalaxyl[3]	W	48	0
Miravis Prime	C	12	7
Miravis Top	C	12	14
Orondis Gold	C	4	5
Presidio	C	12	7
Provysol	C	12	7
Quadris Top	C	12	14
Quash	C	12	1
Ranman	C	12	7
Reason 500 SC	C	12	14
Ridomil Gold EC/SL	C	48	0
Scala SC	C	12	17
Scholar SC	C	0	0
Switch 62.5 WDG	C	12	7
Uniform	W	0	AP
Velum Prime	C	12	7
Vertisan	W	12	7

1 W: Warning, C: Caution, D: Danger; P: Poison
2 AP: At planting.
3 Several formulations are marketed. See the general introduction for more details on fungicides.
4 PHI dependent on application method.

INSECT CONTROL: Sweetpotatoes[1]

Insecticide	Product Amt/A	Seasonal Limit/A	Comments and Other Restrictions
SOIL APPLICATION			
Wireworms			
Belay 2.13 SC	9 to 12 fl oz	12 fl oz	At transplanting or cultivation.
Brigade 2 EC	3.2 to 9.6 fl oz	32 fl oz	At cultivation.
	9.6 to 19.2 fl oz	32 fl oz	Preplant only.
Nurizma 2.5 SC	0.08 to 0.16 fl oz/ 1000 row feet	At planting	Apply as a 5 to 7 inch band at planting and cover completely with soil. For wireworms and whute grubs.
FOLIAR APPLICATION			
Flea Beetles, Tortoise Beetles			
Actara 25 WDG	1.5 to 3 oz	6 oz	Allow 7 days between applications.
Baythroid XL	1.6 to 2.8 fl oz	16.8 fl oz	Limit 2.8 fl oz per 5-day interval. For flea beetles.
Belay 2.13 SC	2 to 3 fl oz	12 fl oz	Allow 7 days between applications. For flea beetles.
Brigade 2 EC	2.1 to 6.4 fl oz	32 fl oz	Limit 2 applications. Allow 21 days between applications.
Exirel 0.83 SC	13.5 to 20.5 fl oz	61.5 fl oz	Allow 5 days between applications.
Harvanta 50 SL	10.9 to 16.4 fl oz	49.2 fl oz	Limit 3 applications. Allow 5 days between applications.
Mustang Maxx	1.76 to 4 fl oz	24 fl oz	Allow 4 days between applications.
Sevin XLR Plus	0.5 to 1 qt	6 qt	Limit 6 applications. Allow 7 days between sprays.
Warrior II	1.28 to 1.92 fl oz	7.68 fl oz	-
Leafhoppers			
Actara 25 WDG	1.5 to 3 oz	6 oz	Allow 7 days between applications.
Baythroid XL	0.8 to 1.6 fl oz	16.8 fl oz	Limit 2.8 fl oz per 5-day interval.
Belay 2.13 SC	2 to 3 fl oz	12 fl oz	Allow 7 days between applications.
Fastac 0.83 EC	1.8 to 3.8 fl oz	11.4 fl oz	Allow 4 days between applications.
Malathion 8	1 to 1.5 pt	2 applications	Allow 7 days between applications.
Miteus 0.42 EC	2 pt	4 pt	Allow 7 days between applications.
Mustang Maxx	1.76 to 4 fl oz	24 fl oz	Allow 4 days between applications.
Portal 0.4 EC	2 pt	4 pt	Limit 2 applications. Allow 7 days between applications.
Sivanto Prime 1.67 SL	7 to 14 fl oz	28 fl oz	Allow 7 days between applications.
Transform 50 WG	1.5 to 2.25 oz	8.5 oz	Limit 4 applications. Allow 14 days between applications.
Torac 1.29 EC	14 to 21 fl oz	42 fl oz	Limit 2 applications. Allow 14 days between applications.
Warrior II	0.96 to 1.6 fl oz	7.68 fl oz	-
Sweetpotato Weevil			
Baythroid XL	1.6 to 2.8 fl oz	16.8 fl oz	Limit 2.8 fl oz per 5-day interval.

1 Generic products available (Appendix G).

WEED CONTROL: Sweetpotatoes

Product Amt/A	Lb A.I./A	Comments
0.5 to 1.6 fl oz Aim 1.9 EW	0.008 to 0.025 carfentrazone	For contact post-emergence control of annual broadleaf weeds and suppression of annual grasses. Can be applied as a preplant, pre-transplant burndown, or before crop emerges to actively growing weeds up to 4 inches tall. Can also be applied post-emergence as a directed hooded application between crop rows. Use min. 10 gal water/A and crop oil 1% v/v. Max. rate 11.6 fl oz/A. PHI = 7 days.
1.3 to 4 pt Command 3ME	0.48 to 1.5 clomazone	For preplant incorporated or pre-emergence control of annual grasses and broadleaves. Use a maximum of 1.5 pt/A in a single application after transplanting and before weed emergence. PHI = 95 days, 125 days if more than 3.3 pt was applied.
6 to 14 lb Dacthal W-75	4.5 to 10.5 DCPA	For pre-emergence control of annual grasses and small-seeded broadleaves. May be sprayed over transplants (slips). Layby applications can be made up to 6 weeks after transplanting.
2 to 4 lb Devrinol 50 DF	1 to 2 napropamide	For control of annual grasses and broadleaf weeds. Apply before transplanting and water-in or incorporate to a depth of 1 to 2 inches in 10 to 50 gal water/A. Can be applied immediately after transplanting. To avoid injury, do not replant with crops not specified on the label for 12 months if using the 4-lb rate. Only herbicide approved for slip (transplant) beds.
1 pt Fusilade-DX 2E	0.25 fluazifop-p	For selective post-emergence control of annual grasses and suppression of perennial grasses. Include 1% v/v crop oil or 0.25% v/v non-ionic surfactant/A. PHI = 55 days. Max. rate is 48 fl oz/A.

(continued on next page)

WEED CONTROL: Sweetpotatoes *(continued)*

Product Amt/A	Lb A.I./A	Comments
16 to 22 fl oz Roundup WeatherMax 5.5L	0.69 to 0.94 glyphosate-salt	For non-selective post-emergence control of annual and perennial grasses and broadleaf weeds. Use only AMS 1 to 2% v/v. Adding a non-ionic surfactant can reduce weed control effectiveness. Min. 30 days before planting any non-labeled crop.
9 to 32 fl oz Select Max	0.07 to 0.24 clethodim	For selective post-emergence of actively growing annual grasses and suppression of perennial grasses. Add crop oil 1% v/v. PHI = 30 days.
0.5 to 1 oz Valor 51DG	0.024 to 0.032 flumioxazin	For post-emergence control of broadleaf weeds and yellow nutsedge. For use on 'Beauregard' variety only. Apply 2 to 5 days before transplanting. Do not use greenhouse-grown transplants. Max. rate 2.5 oz/A.

DISEASE CONTROL: Sweetpotatoes

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Damping-off (*Pythium*) and early season diseases					
Elumin	22	n/a	8 oz	16 oz	Preplant or at planting for Pythium diseases.
MetaStar and metalaxyl[3] generics	4	0	4 to 8 pt	1 app	Preplant or at planting for Pythium diseases. May be applied through drip irrigation.
Orondis Gold 200	49	5	4.8 to 9.6 fl oz	1 app	For pink rot and Pythium leak. Apply over seed pieces in open furrow.
Presidio	43	7	3 to 4 fl oz	12 fl oz	Can be applied as a drench or through drip irrigation at planting; soil-directed applications can be made during the season.
Ranman	21	7	0.42 fl oz/1,000 linear ft	10 total apps	In-furrow.
Ridomil Gold and mefenoxam[3] generics	4	0	1 to 2 pt	2 pt	Preplant or at planting.
Uniform	4/11	-	0.34 fl oz/1,000 linear ft	1 app	In-furrow spray for Rhizoctonia seedling blight and/or Pythium damping off and root rot.
Vertisan	7	7	0.7 to 1.6 fl oz/1,000 linear ft	1 app	In-furrow treatment for Rhizoctonia diseases.
Foliar Diseases					
Aftershock and fluoxastrobin[3] generics	11	7	2 to 3.8 fl oz	22.8 fl oz	
Aprovia Top	7/3	14	10.5 to 13.5 oz	27 oz	Spreading/penetrating adjuvant recommended.
Cabrio and pyraclostrobin[3] generics	11	0	8 to 16 oz	48 oz	
Headline and pyraclostrobin[3] generics	11	3	6 to 12 fl oz[3]	72 fl oz	
Luna Tranquility	7/9	7	11.2 fl oz	54.7 fl oz	
Miravis Prime	7/12	7	6.8 oz	20.4 oz	
Miravis Top	3/7	14	13.7 oz	56 oz	
Omega 500 and fluazinam[3] generics	29	14	5.5 to 8 fl oz	56 fl oz	White mold.
Provysol	3	7	3 to 5 oz	15 oz	
Quadris and azoxystrobin[3] generics	11	0	6 to 15.5 fl oz	6 app	
Quadris Top	11/3	14	8 to 14 fl oz	55.3 fl oz	
Quash	3	1	2.5 to 4.0 oz	4 apps	Make first application prior to row closure.
Ranman	21	7	1.4 to 2.75 fl oz	10 total apps	
Reason	11	14	5.5 to 8.2 fl oz	16.4 fl oz	
Scala	9	17	7 fl oz	35 fl oz	
Switch 62.5 WG	9/12	7	11 to 14 oz	56 oz	

(continued on next page)

DISEASE CONTROL: Sweetpotatoes *(continued)*

Product	FRAC Code[1]	PHI[2] (days)	Amt/A	Seasonal Limits/A	Comments
Velum Prime	7	7	6 to 6.84 oz	13.7 oz	White mold. Apply in-furrow or as side dress. Also nematode suppressive.
Vertisan	7	7	10 to 24 fl oz	72 fl oz	Make initial application at row closure.
Scurf, Black Rot, Sclerotinia Blight, Post-harvest Rot					
Botran 75 W Botran 5F	14	0	2 lb/15 gal water 2.4 pt/15 gal water	1 app	Seed dip. For control of scurf, dip seed in solution for 10 to 15 seconds and plant immediately. Discard unused solution daily.
Botran 75 W Botran 5F	14	0	4.8 oz/1,000 row-feet 5.73 fl oz/1,000 row-feet	1 app	Plant bed application. For control of Sclerotinia blight, spray or sprinkle solution over bedded seed before covering.
Botran 75 W Botran 5F	14	0	0.5 to 1 lb/100 gal water 1.2 pt/100 gal water	1 app	Post-harvest dip. Dip harvested tubers in solution, or spray; do not rinse after treatment. Use low rate for dip. For suppression of rhizopus rot.
Endura	7	10	5.5 to 10 oz	20 oz	Sclerotinia.
Maxim 4 FS	12	0	0.08 to 0.16 oz/cwt	1 app	Seed dip.
Mertect 340 F	1	0	3.3 qt/100 gal water	1 app	Seed dip.
Scholar SC		0	16 to 32 fl oz/100 gal	1 app	Postharvest dip.
Vertisan	7	7	10 to 24 fl oz	72 fl oz	Make initial application at row closure.

1 Products with numerical FRAC codes must be alternated or tank-mixed with products that have a different FRAC code to discourage resistance development. See product label for maximum number of consecutive applications allowed. Refer to the table on pages 22-24 for more information on FRAC codes.

2 Pre-harvest interval.

3 Use higher rate when pressure is severe.

Tomatoes

Nightshade family (Solanaceae): *Solanum esculentum*

For information on tomatoes see “Fruiting Vegetables” section on page 86

Appendix A

Production and Marketing Information Online

Internet websites contain an incredible wealth of useful information of interest to commercial vegetable growers in Kentucky and surrounding states. Below is a list of topics from over 50 websites considered to be of particular value to commercial growers. Links to these sites can be found at:

http://www.uky.edu/hort/documents-list-commercial-vegetable

Warning!

Use this information with caution and at your own risk. You should be very careful about using any variety, fertilizer, or pesticide recommendation from another region or distant state. Some pesticides may be legal only for use in that particular state or production region. Varieties that perform well in another state may or may not perform well in Kentucky.

Remember that Internet addresses sometimes change. Those listed here worked as of November, 2019.

University of Kentucky Martin-Gatton College of Agriculture, Food and Environment

University of Kentucky Martin-Gatton College of Agriculture, Food and Environment: Provides links to most UK agriculture departments and their publications.

- http://www.ca.uky.edu/

Horticulture Department: Has most of UK's vegetable crop publications linked under "Commercial Horticulture" and "Vegetables".

- http://www.uky.edu/hort/

Department of Entomology: Fact sheets on Kentucky's vegetable insect and mite pests.

- https://entomology.ca.uky.edu/entfacts/

Center for Crop Diversification: Provides research updates, profiles of promising new crops, and marketing information for Kentucky.

- http://www.uky.edu/Ag/CCD/

Ag. Weather Center: An excellent source of current and historical weather information.

- wwwagwx.ca.uky.edu/

Vegetable Production Guidelines for Commercial Growers: This publication (ID-36) and most other UK extension publications available online.

- http://www.uky.edu/hort/documents-list-commercial-vegetable

Integrated Pest Management (IPM) guidelines: Detailed production information and pest management strategies for Kentucky sweet corn, cabbage, peppers, and pumpkins.

- http://ipm.ca.uky.edu/vegetableipm

Vegetable and Melon Enterprise Budgets for Kentucky: These interactive crop budgets provide average costs and returns for most vegetable crops and allows users to enter their own cost and price figures to instantly estimate returns per acre.

- http://www.uky.edu/ccd/tools/budgets

General Vegetable Production Information from Other States

Southeastern U.S. Vegetable Crop Handbook: A collaboration of several Southeastern U.S. states contains useful production information.

- https://www.growingproduce.com/southeasternvegetablecrophandbook/

University of Florida: Extensive vegetable production information, petiole sap testing for nitrogen nutrition, alternative crops, newsletter, and Florida transplant producers.

- http://edis.ifas.ufl.edu/topic_commercial_vegetable_production

Mississippi State University Greenhouse Information: Links to Greenhouse Tomato Handbook, Starting Vegetable Transplants, and to other sources of information on greenhouse vegetable production and pest management.

- http://extension.msstate.edu/agriculture/crops/commercial-horticulture

Weekly Vegetable IPM and Other Newsletters

Kentucky Pest News: Access to the current and back issues of KPN.

- http://plantpathology.ca.uky.edu/extension/kpn

Illinois Fruit & Vegetable News: Produced at the University of Illinois.

- https://ipm.illinois.edu/ifvn/

Organic Vegetable Production

Appropriate Technology Transfer for Rural Areas (ATTRA): A number of extensive online organic vegetable production guides.

- https://attra.ncat.org/horticultural.html#Vegetables

Resources for CSA Producers from the USDA: Information on organic food production, sustainable agriculture and community supported agriculture (CSA).

- https://pubs.nal.usda.gov/csa-resources-farmers

USDA National Organic Program (NOP): Links to new NOP standards.

- https://www.ams.usda.gov/about-ams/programs-offices/national-organic-program

Kentucky Organic Certification: Kentucky Department of Agriculture's organic certification program (forms and information).

- http://kyagr.com/marketing/organic-marketing.html

Production and Marketing Information Online Continued

University of Kentucky: Information on organic crop certification.

- http://www.uky.edu/ccd/production/system-resources/organic

Sustainable Agriculture Research and Education (SARE): A grower focused organization that is affiliated with land grant universities around the country. Excellent resource for growers.

- http://www.sare.org/

Marketing and Market Prices

UK's Marketing Options for Commercial Vegetable Growers: Publication # ID-134; this is written with tobacco growers in mind. It compares and contrasts most of the available produce marketing options.

- http://www2.ca.uky.edu/agcomm/pubs/id/id134/id134.pdf

Kentucky Horticulture and New Crops Marketing: A number of other marketing fact sheets for vegetable and fruit crops.

- http://www.uky.edu/ccd/marketing

USDA Wholesale Price Information: The same wholesale prices plus specialty, auction, and farmers' market reports.

- https://www.ams.usda.gov

Kentucky Farmers' Markets: Kentucky Department of Agriculture provides information on farmers' markets throughout the state.

- http://www.kyagr.com/marketing/farmers-market.html

USDA Grading Standards: Fruit and vegetable grading standards.

- https://www.ams.usda.gov/grades-standards/vegetables

USDA Direct Marketing Home Page: The USDA hosts this site.

- https://www.nal.usda.gov/main

Kentucky Department of Agriculture: Includes links to Horticultural Division, Organic Certification, and KY Produce Shipper's Directory. Information about Kentucky's vegetable marketing cooperatives, a Farmers' Market Directory, and guidelines for "Kentucky Proud" logo program.

- kyagr.com

KDA Country Store: The Department of Agriculture helps Kentucky producers build their own website and hosts those sites at no charge.

- http://kyagr.com/buyky/webpage-builder.html

Kentucky Farm Bureau: Provides a link to its map and directory of Kentucky Certified Roadside Farm Markets.

- kyfb.com

Post-harvest and Food Safety (handling, cooling, grading, packaging, etc.)

Kentucky Department of Agriculture Good Agricultural Practices (GAP) Program: Good food safety information specific to Kentucky growers.

- http://www.kyagr.com/marketing/GAP.html

Cornell University Food Safety: Some of the best information on food safety and good agricultural practices for growers is available in the publication: Food Safety Begins on the Farm–A Grower's Guide. Excellent resource.

- https://gaps.cornell.edu/educational-materials/

Appendix B

Secondary Nutrients and Micronutrients

Calcium—Calcium levels in soils vary with soil pH and cation exchange capacity (CEC). To avoid developing soil conditions that may lead to low levels of available calcium and low calcium uptake by some crops, have soil tested frequently. Apply lime to obtain the recommended soil pH at least six months before growing the crop. See the publication "Lime and Fertilizer Recommendations" (AGR-1) for lime rates to achieve desired pH changes.

Magnesium—Magnesium levels in Kentucky soils range from very high (loess-derived soils) to somewhat low (some sandstone-derived and recently cleared soils). Magnesium is included as part of the routine soil test. For vegetable crops, a test level of 80 pounds per acre is considered the minimum, and 200 pounds per acre is recommended for staked tomatoes and muskmelons. If both lime and magnesium are needed, dolomitic lime should be applied. If dolomitic lime is not available or when lime is not needed and magnesium is recommended, other sources of magnesium such as magnesium oxide or Epsom salts (magnesium sulfate) are available for broadcast or row application. Refer to the "Vining Crops" chapter for magnesium application rates. Magnesium deficiencies are readily identifiable in many plants. Typically deficiencies show up as interveinal chlorosis on older leaves.

Iron, Copper, Manganese—For horticultural crops, we have not measured consistent responses to soil-applied iron, copper, or manganese. To verify a suspected deficiency of iron, copper or manganese, have an analysis of plant tissue appropriate for the crop carried out with a commercial lab through your county Extension agent. Responses to foliar applications of iron, copper, or manganese, after diagnosis of a deficiency, have been superior to soil applications. Many deficiencies of iron, copper and manganese show similar signs as magnesium deficiencies (ie. interveinal chlorosis); however, typically micronutrient deficiencies appear first in new growth, whereas magnesium deficiencies will tend to first appear in older growth.

Sulfur—We have not measured a response to sulfur application on horticultural crops in Kentucky. However, cole crops established early in the spring on soils that tend to be cool and moist may be susceptible to low amounts of available sulfur. A meaningful and suitable soil test for sulfur is not available in Kentucky because of several factors affecting available sulfur levels in soils. It is suggested that sulfur-containing fertilizer be used where cole crops are to be grown as they are high sulfur users.

Boron—Yield responses to boron have been observed only for certain crops under some conditions. A boron soil test is available in Kentucky upon request through your county Extension agent. Boron should only be applied when soil test boron is less than 1 pound per acre. Boron is normally applied at the rate of 1 to 2 pounds of actual boron per acre.

Zinc—Zinc deficiency in snap beans and sweet corn may be significant in Central and South-central Kentucky. The test for zinc is now included in the routine soil test. The results of this test, in conjunction with soil test results for pH and phosphorus, can help farmers make needed applications of zinc fertilizer. When zinc is recommended and equipment is available, banding can reduce costs by two-thirds over a broadcast application. Zinc sulfate (36% Zn) is usually applied at 30 to 90 pounds per acre when broadcast. Chelated zinc (14%) can be applied at 15 to 40 pounds per acre. For a foliar spray, use chelated zinc at 3⁄4 to 1 pound in 100 gallons of water. See also the "Fertilizing" section of the "Sweet Corn" chapter.

Appendix C

Conversion Tables for Use of Pesticides on Small Areas

LIQUID MATERIALS

Approximate Rate Per:	Recommended Rate/A							
	1 pt	1 qt	2 qt	1 gal	25 gal	50 gal	75 gal	100 gal
1,000 sq ft	¾ tbs	1½ tbs	3 tbs	6 tbs	4½ pt	4½ pt	7 qt	9 qt
100 sq ft	¼ tsp	½ tsp	1 tsp	2 tsp	1 cup	1 pt	1½ pt	1 qt

DRY MATERIALS

Approximate Rate Per:	Recommended Rate/A										
	1 lb	2 lb	3 lb	4 lb	5 lb	6 lb	8 lb	10 lb	100 lb	200 lb	400 lb
1,000 sq ft	2¼ tsp	4½ tsp	2¼ tbs	3 tbs	4 tbs	4½ tbs	2⁄5 cup	½ cup	2¼ lb	4½ lb	9 lb
100 sq ft	¼ tsp	½ tsp	¾ tsp	1 tsp	1¼ tsp	1½ tsp	1¾ tsp	2 tsp	¼ lb	½ lb	1 lb

Appendix D

English Measurement Units

3 teaspoons (tsp)	=	1 tablespoon
2 tablespoons (tbs)	=	1 fluid ounce
16 tablespoons (tbs)	=	1 cup
8 fluid ounces (fl oz)	=	1 cup
2 cups (c)	=	1 pint
2 pints (pt)	=	1 quart
4 quarts (qt)	=	1 gallon (gal)

Appendix E

Fumigants For Vegetable Crops

See also "Soil Fumigants for Control of Nematodes and Soilborne Diseases" on page 21.

Trade Name	Common Name	Rate/A (gal)	Target Pests	Timing (Plant-back)[1]	Restricted Use	Re-Entry Interval
Chloropicrin	chloropicrin (99.5%)	10.9 to 12.8	nematodes, soilborne diseases	2 to 3 weeks	Yes	5 days
K-Pam HL	metam-potassium (54%)	15 to 62	weeds, nematodes, soilborne diseases	2 to 3 weeks	Yes	5 days
Telone II	1,3-dichloropropene (97.5%)	9 to 12	nematodes	1 to 2 weeks	Yes	5 days
Telone C-17	1,3-dichloropropene (81.2%) + chloropicrin (16.5%)	10.8 to 17.1	nematodes, soilborne diseases	1 to 2 weeks	Yes	5 days
Telone C-35	1,3-dichloropropene (63.4%) + chloropicrin (34.7%)	13 to 26	nematodes, soilborne diseases	2 to 3 weeks	Yes	5 days
Vapam HL or Sectagon-42	metam-sodium (42%)	37.5 to 75	weeds, nematodes, soilborne diseases	2 to 3 weeks	Yes	5 days

[1] *Dissipation of fumigants will be slower in cool, wet, or heavy soils. Under these conditions, allow more time for materials to escape soil, and aerate by tillage before planting. Failure to aerate fully can result in severe plant injury or death. If no fumigant odor is detected, aeration is generally sufficient.*

Appendix F

Generic and Alternative Fungicides

Active Ingredient	Generics	Manufacturer
Azoxystrobin Original Product: Quadris (Syngenta)	Acadia 2SC	Atticus
	Aframe	Syngenta
	Arius	Sipcam Agro USA
	AzoxyStar	Albaugh/Agri-Star
	Azoxystrobin 100 ST	
	Azoxyzone	LG Life Sciences
	Azteroid	Vive Crop Protection
	Dynasty	Syngenta
	Equation	FMC
	Gold Rush	Altitude Crop Innovations
	Heritage	Syngenta Professional Products
	Mazolin	AgBiome Innovations
	Satori	Loveland
	Tetraban	WinField United
	Trevo	Innvictis Crop Care
	Willowood Azoxy2SC	Willowood
Chlorothalonil Original Product: Bravo WeatherStik 720 SC (Syngenta)	Cercos	Sipcam Agro USA
	Chloronil 720	Syngenta
	Chlorothalonil 720 SC	Arysta
	Echo 720	SipcamAdvan
	Equus 720 SST	ADAMA
	Initiate 720	Loveland
	Praiz	WinField United
	Vabro	WinField United
	Original Product: Bravo Ultrex 82.5 WDG (Syngenta)	
	Echo 90 DF	SipcamAdvan
	Original Product: Bravo ZN (Syngenta)	
	Echo Zn	Sipcam Agro
	Initiate Zn	Loveland
Fludioxonil Original Product: Cannonball (Syngenta)	Cannonball	Syngenta
	Emblem	NuFarm
	Maxim	Syngenta
	Scholar	Syngenta
Fluoxastrobin Original Product: various	Aftershock	Loveland
	Evito	UPL
	Tepera	UPL
Fluazinam Original Product: Omega 500F (Syngenta)	Lektivar	AgBiome Innovations
	Omega 500F	Syngenta
Fosetyl-Al Original Product: Aliette (Bayer)	Aliette	Bayer
	Linebacker	Tessenderlo Kerley
Iprodione Original Product: Rovral 4F (Bayer)	Iprodione 4L AG	Arysta
	Meteor	United Phosphorus
	Nevado 4F	ADAMA
	Rovral 4F Fungicide	FMC

(continued on next page)

Generic and Alternative Fungicides Continued

Active Ingredient	Generics	Manufacturer
Mancozeb Original Product: Dithane (Dow)	Dithane F45	Corteva Agriscience
	Dithane M45	
	Fortuna	Agria Canada
	Koverall	FMC
	Manzate Max	UPL NA Inc.
	Manzate ProStick	UPL NA Inc.
	Penncozeb 80WP	UPL NA Inc.
	Potato Seed Treater	Loveland Products
	Roper DF	Loveland Products
	Roper DF Rainshield	Loveland Products
Mefenoxam Original Product: Ridomil Gold SL (Syngenta)	Anchor 3L ST	Albaugh
	Apron XL	Syngenta
	Ridomil Gold SL	Syngenta
	Thrive 4M	Albaugh
	Ultra Flourish	Nufarm
Metalaxyl Original Product: Metastar (LG LifeSciences)	Axyl-Shield ST	Sharda
	Metalaxyl 2E AG	Albaugh
	Metastar 2E	LG Life Sciences
	Xyler FC	Vive Crop Protection
Myclobutanil Original Product: Rally (Dow)	Rally 40WSP	Corteva Agriscience
	Sonoma 40WSP	Albaugh
Phosphorus Acid Original Product: ProPhyt (Helena)	Fosphite	Corteva
	Fungi-Phite	Verdesian
	K-Phite	Plant Food Systems
	Phostrol	Nufarm
Propiconazole Original Product: Tilt (Syngenta)	Arysta Propiconazole 41.8% EC	Arysta
	Bumper 41.8 EC	ADAMA
	Bumper ES	ADAMA
	Fitness	Loveland
	Marazo	AgBiome Innovations
	Omni	Helena
	Propiconazole 3.6 EC	Repar
	Propiconazole 41.8% EC	Helena Chemical
	Propicure	WinField United
	Propimax EC	Dow Agrosciences
	Propi-Star	Albaugh
	Shar-Shield PPZ	Sharda USA
	Slant	Atticus
	Tide Propiconazole 41.8% EC	Tide International USA
	Topaz	WinField United
	Vigil	Innvictis Crop Care
	Willowood Propicon 3.6EC	Willowood
Propiconazole + Azoxystrobin Original Product: Quilt Xcel (Syngenta)	Aquila	Atticus
	Avaris 2 XS	Helena
	AzoxyProp	Tigris
	Cover XL	Albaugh
	MiCrop	Albaugh
	Quilt Xcel	Syngenta
	Xiphosin	AgBiome Innovations

(continued on next page)

Generic and Alternative Fungicides Continued

Active Ingredient	Generics	Manufacturer
Sulfur Original Product: Various products and manufacturers	Cosavet DF	Sulphur Mills
	Microfine Sulfur	Loveland
	Microthiol Disperss	United Phosphorus
	Suffa	Drexel
	Sulfur 80	Arysta
Tebuconazole Original Product: Folicur 3.6F (Bayer)	Barrier	Real Farm Technologies
	Monsoon	Loveland
	Muscle	Sipcam Agro USA
	Onset 3.6L	Winfield Solutions
	Orius 3.6F	ADAMA
	Tebu-Crop 3.6F	Sharda USA
	Tebucon 3.6F	Repar
	Tebustar 3.6L	Albaugh/Agri-Star
	Tebuzol 3.6F	United Phosphorus
	Toledo	Rotam North America
	Willowood Teb 3.6 SC	Willowood
Thiophanate-methyl Original Product: Topsin M 70WDG, 70WP, WSB (United Phosphorus)	Cercobin	FMC
	Incognito 85 WDG	ADAMA
	Nufarm T-Methyl 70 WSB	Nufarm
	Thiophanate-Methyl 85WDG	ADAMA
	Original Product: Topsin 4.5FL (United Phosphorus)	
	Incognito 4.5F	ADAMA
	Nufarm T-Methyl 4.5F	Nufarm

Appendix G

Generic Insecticides

Active Ingredient	Generics	Manufacturer
Abamectin Original Product: Agri-Mek 0.15 EC (Syngenta)	Abacus 0.15 EC	Rotam
	Abamectin 0.7 SC	Willowood
	Abamex 0.15EC	Nufarm
	Abba 0.15 EC	Adama
	Abba Ultra 0.3 EC	Makhteshim
	Agmectin 0.15 EC	Tide
	AgriMek 0.7 SC	Syngenta
	Averland 0.7 FC	Vive
	Avow 0.15 EC	Innvictus
	Enterik 0.15 LV	Atticus
	Reaper 0.15 EC Reaper Advance 0.15 EC	Loveland
	Timectin 0.15 EC	Tide Intl.
Acephate Original Product: Orthene 90 SP (Valent)	Acephate 90 Prill	Adama
	Acephate 90 WDG, 90 WSB	Loveland, Tide
	Acephate 97 UP	United Phosphorous
	Acephate 97 WDG	Adama
	Bracket 90 WDG, 97 WDG	Winfield
	Livid 90 Prill, 97 Prill	Innvictus
	Orthene 97	Amvac
Acetamiprid Original Product: Assail 30 SG, 70 WP	Anarchy 30 SG, 70 WP	Loveland
	Arvida 30 SG, 70 WP	Atticus
	Azomar 30 SG	AgBiome Innovations
	Intruder Max 70 WP	United Phosphorous
	Quasar 8.5 SL	Atticus
Bifenazate Original Product: Acramite 50 WS	Actuate 2 SC	Atticus
	Banter 50 WDG, 4 SC	United Phosphorous
	Bifenamite 50 WDG, 4 SC	Agri Star
	Bifenazate 50 WDG, 4 SC	Willowood
	Bizate 50 WDG	Loveland
	Envenerate 4 SC	Atticus
	Floramite SC	OHP
	Vigilant 4 SC	McDermid
Bifenthrin Original Product: Brigade 2 EC, Capture 2 EC (FMC)	Battalion 2EC, 10 WSP, LFC	Atticus
	Bi-Dash 2 EC	Sharda
	Bifen 2 AG Gold	Direct AG Source
	Bifen 25% EC	Tacoma
	Bifender FC	Vive
	Bifenthrin 2 EC	Aceto, Willowood
	Bifenture 2 EC	United Phosphorous
	Discipline 2 EC	Amvac
	Fanfare 2 EC, ES	Adama
	Frenzy Veloz	Real Farm
	Lancer 2 EC	Albaugh
	Nirvana RTU	Innvictus
	Reveal 2 EC	Innvictus
	Seguro	Sharda
	Sniper 2 EC, LFR	Loveland
	Tundra 2 EC	Winfield
	Xpedient 2 Ec	Amvac
Carbaryl Original Product: Sevin 4L, 80 S, SL, XLR (Bayer)	Carbaryl 4 L	Drexel, Loveland

(continued on next page)

Generic Insecticides Continued

Active Ingredient	Generics	Manufacturer
Chlorfenapyr Original Product: Pylon 1 (BASF)	Piston 2	Atticus
Chlorpyrifos Original Product: Lorsban 4 E, 15 G, 75 WDG, Advanced 3.76 E (Dow AgroSciences)	Chloryrifos 4 E	Adama, Drexel, Nufarm
	Govern 4 E	Tenkos
	Hatchet 4 E	Dow AgroSciences
	Saurus 15 G	Helena
	Vesper 4 E	Innvictus
	Vulcan 3.76 E	Adama
	Warhawk 4 E	Loveland
	Whirlwind 4 E	Helena
	Yuma 4 E	Winfield
Cyfluthrin Original Product: Baythroid XL 1 EC, Renounce 20 WP (Bayer)	Tombstone 2 E	Loveland
	Tombstone Helios 2 E	Loveland
Cypermethrin Original Product: Ammo (discontinued)	Battery 2.5 EC	Winfield
	Cypermethrin 2.5 EC	TENKOZ
	Holster 2.5 EC	Loveland
	Up-Cyde 2.5 EC	UPL
Dinotefuran Original Product: Vemon 70 SG	Certador 0.89 SC	BASF
	Scorpion 35 SL	Gowan
Esfenvalerate Original Product: Asana XL 0.66 EC (Dupont)	S-FenvaloStar 0.66 EC	LG Life Sciences
Gamma-cyhalothrin Original Product: Proaxis 0.5 EC (Cheminova)	Declare Insecticide 0.5 EC	Cheminova
Hexythiazox Original Product: Hexygon, Onager, Savey (Gowan)	Hexamite 1E	Albaugh
	Hexcel 50 DF	Atticus
	Hexy 1 E, 2 E	Sharda
	Ruger 1 EC	Atticus
Imidacloprid Original Product: Admire Pro 4.6 F (Bayer)	Acronyx 4 F	Atticus
	Advise 2 FL	Winfield
	Alias 2 F, 4 F	Adama
	Imidacloprid 2 SC, 4 SC	Willowood
	Lada 2 F	Rotam
	Macho 2 FL, 4 F	Albaugh
	Malice 75 WSP	Loveland
	Midash 2 SC	Sharda USA
	Montana 2 F, 4 F	Rotam NA
	NuPrid 2 F, 2 SC, 4 F Max, 4.6 F	Nufarm
	Provoke 4 F	Innvictus
	Prey 1.6 F Sherpa 1.6 F Widow 2 F Wrangler 4 F	Loveland
	Viloprid FC 1.7	Vine Crop Protection

(continued on next page)

Generic Insecticides Continued

Active Ingredient	Generics	Manufacturer
Lambda-cyhalothrin Original Product: Karate 1 EC, Warrior with Zeon 1 ME, ll 2 ME (Sygenta)	Cavalry ll 2.08 SC	Growmark
	Firestone 1 CS	Altitude Crop Innovations
	Grizzly Z 1 CS	Winfield
	Kendo 1 EC	Helm
	Lambda-CY AG	Direct AG Source
	Lambda CY 1 EC	United Phosphorous, Willowood
	Lambda-Cyhalothrin 1 EC	Nufarm
	LambdaStar 1 EC, 1 CS	LG Life Sciences
	Lamcap ll 1 CS	Syngenta
	Paradigm 1 VC	Winfield United
	Province ll 2 SC	TENKOZ
	Ravage 1 EC	Innvictus
	Serpent 1 EC	Atticus
	Silencer 1 EC	Adama
Methomyl Original Product: Lannate SP, LV (Corteva)	Nudrin SP, LV	Rotam
	Lanveer LV	Innvictus
Methoxyfenozide Original Product: Intrepid 2 F (Corteva)	Inspirato 2 F	Atticus
	Insurgent 2 F	Altamont
	Invertid 2 F	Loveland
	Troubadour 2 F	Helena
	Turnstyle 2 F	UPL
	Vexer 2 F	Innvictus
	Zylo 2 F	UPL
Permethrin Original Product: Pounce 3.2 EC (not available) (FMC)	Arctic 3.2 EC	Winfield
	Perm-Up 3.2 EC	United Phosphorous
	PermaStar AG 3.2 EC	LG Life Sciences
	Permethrin 3.2 EC	Loveland, TENKoz, Helena
Pymetrozine Original Product: Fulfill 50 WDG (Syngenta)	Seville 50 WDG	Atticus
Pyriproxyfen Original Product: Distance, Knack 0.86 EC (Valent)	Cusack 0.86 EC	Atticus
	Farewell	Adama
	Reemit 0.86 EC	Atticus
Spinosad Original Product: Spinor 2 SC, Tracer 4 SC (Corteva)	Seduce	Certis
Thiamethoxam Original Product: Actara 25 WDG (Syngenta)	Artist 25 WDG	Sharda

Appendix H

Organic Manures and Fertilizers

Animal manure contributes more to the soil than just nitrogen, phosphorus, and potassium. Continued use of manure builds organic matter in soils and improves soil structure. This modification of soil structure helps improve water holding capacity, aeration, friability, and drainage. In addition, many trace nutrients needed for optimal plant growth are available from manure. Plant nutrients are also released more slowly and over a longer period of time than from most commercial fertilizers.

Disadvantages of using manure are the handling and transportation problems associated with large amounts of manure required to obtain sufficient quantities of nutrients for vegetables. The use of fresh manure may also introduce new weeds into fields since certain weed seeds remain alive even after passage through animals. Another concern is that the careless use of manure can expose fresh produce to human pathogens such as E. coli, which can cause serious illness. Food safety must be a primary consideration in any vegetable operation but especially where manure are being used.

General Considerations

Fresh Vegetables, Not Fresh Manure

Manure cannot be used fresh (raw) if you intend to plant directly into it; composting results in a more readily usable form of manure. Composting will also destroy many weed seeds that could otherwise be introduced into new fields or gardens. Composting requires that the temperature reach 131 to 170°F for at least 15 days, and the compost must be turned 5 times. For more information on the composting process, see UK Extension publication HO-75, *Home Composting: A Guide to Managing Home Organic Waste*. This guide along with other home and commercial vegetable publications are available from the Horticulture Department's website at uky.edu/Agriculture/Horticulture/homeveggies.html. If fresh manure is used on soil, it should be worked in as soon as possible or covered with other organic materials such as straw, hay, or grass clippings to prevent the loss of nitrogen through leaching. No fresh manure may be used during the year of harvest for certified organic production so you may want to plant a green manure or cover crop on this ground for the first year (see website above for information on Kentucky cover crops). See also kyagr.com/marketing/plantmktg/organic/index.htm for detailed information on organic certification in Kentucky. This allows soil microbes to start the decomposition process that regulates nutrient availability and prevents burning of young plant roots. It also substantially reduces the chance of produce *E. coli* and *Salmonella* contamination.

Caution: Fresh manure is best applied and plowed down the fall before planting. There should be at least 120 days between manure application and planting for vegetable crops in which the edible portion touches the ground.

Remember that some types of animal manure have higher nitrogen contents than others (see Tables 1 and 2). These include horse, sheep, chicken, and rabbit manure. These are sometimes referred to as "hot" and are best used after composting. Cow and hog manures are considered "cold" because of their lower nitrogen levels.

Application

Composted manure can be broadcast and worked into fields or worked into rows and beds for various vegetable crops. A general recommendation for vegetable gardens is to broadcast poultry, sheep, cow, or horse manure at 25 to 100 pounds per 100 square feet (approximately 5 to 20 tons per acre). This amount may need to be supplemented with 1 to 2 pounds of a complete inorganic fertilizer such as 10-10-10. Organic growers can supplement with ground rock phosphate or raw bone meal to obtain phosphorus required (see below). For crops such as melons, squash, and cucumbers, composted manure can be worked directly into planting hills and mixed thoroughly with the soil.

Nutrient Contents

It is important to remember that nutrient contents in manure vary widely according to age of the animals, feed used, moisture content, degree of decomposition, and the amount of litter or bedding material mixed in with the manure. The only really accurate way of determining the nutrient content of the manure you are using is through laboratory analysis. You may need to adjust your application rates up or down according to what you know about the age, quality, and moisture content of the manure.

When buying or getting ready to spread manure, remember that moisture content greatly affects the total pounds of nutrients in a ton of material. For example, broiler manure at 25% to 30% moisture when removed from the house will contain about 34 pounds of nitrogen, 37 pounds of phosphate, and 31 pounds of potash per ton. But a ton of fresh manure at 75% moisture will contain only 27, 28, and 14 pounds of these nutrients, respectively. At 75% moisture you will be hauling around 1,500 pounds of water and only 500 pounds of solid material. Not all nutrients in manure are available to crops during the season of application. In poultry manure, for example, 90% of the N, most of the potassium, but only half of the phosphorus becomes available in the first year.

Because phosphorus in manure must decompose before it becomes available and because it is not very mobile in soil, broadcasting manure is not considered a very efficient

way of applying this element for establishment of vegetable crops. For poultry manure, phosphorus and potassium portions are considered to be about 50% to 75% as effective as they are in commercial fertilizers during the year of application; the remainder is released as the litter decomposes. Supplement manures with a complete inorganic fertilizer or with an organically approved material such as bone meal or ground rock phosphate.

How to Use and Convert Fertilizer Recommendations in this Publication

Plant nutrient requirements are provided in the "Fertilizer" tables under each crop in this publication. These nutrients are expressed in terms of the amounts of nitrogen (N), phosphorus or phosphate (P_2O_5), and potassium (K_2O) required by the crop. Amounts of phosphorus and potassium recommended vary according to what may already be present in the soil. For this reason, both conventional and organic growers should always have their soil tested, preferably in the fall or early spring. Soil test sample boxes and instructions are available from your county Extension office.

To calculate the amount of manure required for application on a sweet corn crop, for example, first find the suggested nutrient application rates in the "Fertilizer" table in the "Sweet Corn" chapter. **Warning:** Manure applications should never exceed the total nitrogen requirements of a crop in an attempt to satisfy phosphorus and potassium requirements—burning of the roots and leaves could occur.

Nitrogen First

We will choose nitrogen as our "priority" nutrient, which will be used to limit the total amount of manure to be used; i.e., we will calculate the manure requirements based only on the nitrogen recommendation. Although most manure high in nitrogen is also high in potassium (Tables 1 and 2), additional phosphorus may need to be obtained from other sources. Because soil and plant nitrogen tests are not widely used in Kentucky and because much of the nitrogen in soils is used or lost from one season to the next, we make a blanket recommendation of 80 to 100 pounds of N per acre for sweet corn preplant. When commercial fertilizers are used, this amount is applied before planting and is supplemented by a sidedressing of 40 to 50 pounds of N per acre when plants are about knee-high.

Consider the Source

Now consider the source, moisture content, and quality of the manure or organic material to be used. If we are using a dry or composted material containing little or no moisture, we should use Table 2 to make the necessary calculations.

Making Conversions

We have decided to use the lower N level of 80 pounds per acre because we feel our soil may still have some residual N from last year's bean crop that was grown on this plot. We have found a source of composted poultry manure and plan to use it as our nutrient source. To calculate the manure required to provide the required 80 pounds of nitrogen, look at Table 2 under poultry; the N content is 3.2%. Divide the 80 pounds by 3.2 = 25 and multiply the result by 100 = 2,500 pounds. This is the amount of poultry manure required to obtain the 80 pounds per acre of nitrogen recommended. To convert to tons, simply divide again by 2,000 (2,500 ÷ 2,000 = 1.25 tons).

In this example we will have obtained 80 pounds of nitrogen together with 130 pounds of phosphorus (P_2O_5) and 45 pounds of potassium (K_2O). The amount of P_2O_5, and K_2O are calculated for the 2,500 pounds of manure by multiplying 2,500 by the appropriate percentages in Table 2 and then dividing by 100. The amount of P_2O_5, for example, is 2,500 pounds x 5.2 = 13,000 divided by 100 = 130 pounds. For the amount of K_2O, multiply 2,500 pounds x 1.8 and then divide by 100 = 45 pounds.

Additional Phosphorus

Now suppose that the soil is very low in phosphorus and the soil test suggests applying 180 pounds of phosphorus. We have obtained 130 pounds of phosphorus from the poultry manure and need an additional 50 pounds, but we do not want to apply much more nitrogen.

Looking at Table 2 we decide to supply our phosphorus using raw bone meal, which is 22% P_2O_5 and 3% N. Dividing 50 pounds of P_2O_5 by 22 = 2.27 and multiplying by 100 = 227 pounds. Thus, 227 pounds of raw bone meal/acre will supply 50 pounds of P_2O_5. Performing a similar calculation for the N tells us that we will only obtain about 7 (6.8) pounds of N/acre using raw bone meal. Use this same means of calculation if additional potassium is needed.

Note: *Information in Tables 1 and 2 should be used only as guidelines. Nutrient contents for manures vary greatly. The figures represented are averages from a range of possible values.*

Table 1. Nutrients in FRESH animal manure.

Source	Water Content	Average Nutrient Composition (percent of fresh weight) N	P_2O_5	K_2O
Beef cattle	80	0.70	0.45	0.55
Dairy cattle	84	0.60	0.25	0.60
Horses	60	0.60	0.25	0.45
Hogs	75	0.50	0.35	0.65
Sheep	65	1.05	0.35	0.95
Laying hens	75	1.00	1.25	0.50
Broilers (litter)[1]	30	2.95	2.75	1.85

[1] *Some broiler producers use Roxarson and Nitarsone in their feed mixes as medications. Growers using litter containing these products cannot sell produce grown with this manure as certified organic in Kentucky.*

Table 2. Nutrient contents of DRY manures and organically approved fertilizer materials.

Source	Average Nutrient Composition (percent dry weight) N	P_2O_5	K_2O
Dairy cows	1.3	0.9	3.0
Feedlot cattle	1.7	1.2	3.0
Horse	2.3	0.9	1.7
Poultry	3.2	5.2	1.8
Sheep	3.5	1.4	3.5
Hogs	3.5	0.5	0.7
Goat	1.5	1.5	3.0
Rabbit	2.4	1.4	0.6
Tobacco stems[1]	1.5	0.5	7.0
Bat guano	10.0	2.0 to 4.0	0 to 2.0
Blood meal	13.0 to 14.0	2.0	1.0
Bone meal, raw	3.0	22.0	-
Bone meal, steamed	1.0 to 2.0	11.0 to 15.0	-
Cottonseed meal	6.0	0.4 to 3.0	1.5
Fish meal	10.0	6.0	-
Fish emulsion	5.0	2.0	2.0
Feather meal	12.0	0	0
Soybean meal	7.0	1.2	1.5
Tankage[1]	7.0	10.0	1.5
"Soft" rock phosphate	0	14.0 to 16.0	0
Greensand	0	0	3.0
Phytamin 800	7.0	0	0

[1] *Not cleared for certified organic production. Sewage sludge should not be used for vegetable crops because of possible heavy metal and E. coli contamination.*

Appendix I

Disinfection and Treatment of Vegetable Seeds

Hot Water Treatment (most vegetable seeds)

Seeds many vegetables can be soaked in hot water to reduce populations of seedborne bacteria and fungi. Germination may be reduced to some degree, so some experimentation with small seed lots should be carried out before treating large amounts of seed. Cucurbits other than cucumber may be severely harmed by hot water treatment and should be disinfected by other methods. In general, use fresh seed for this process, as research indicates that viability of older seed (more than 1 year old) is drastically reduced by treatment with hot water. Bacterial and fungal pathogens associated with the embryo will not be affected by hot water soaking (bacterial canker of tomato, for example, can infect the embryo of the tomato seed along with being associated with the seed coat), nor will TMV be eradicated.

Water temperature and soaking time differ by species (Table 1), and relatively tight control of temperature is critical to the success of this method. A water bath capable of holding temperature within a reasonable range is a required piece of equipment, along with a quality canning thermometer to monitor temperature. A 5-degree drop in ideal temperature may allow some pathogens to survive on seed, while a 5-degree increase in water temperature may kill some or all of the seed being treated. The same rigor should be observed for soaking time.

Guidelines published by the University of Illinois suggest that seed should be pre-warmed before beginning the actual hot water treatment. This can be done by placing seed in a weighted cheesecloth bag and soaking in 100°F water for 10 minutes. The bag may need to be squeezed to remove air bubbles—maximum contact of water and seed is critical.

For the next step, place the bag containing the pre-warmed seed into a water bath set to the temperature recommended for the vegetable seed being treated (Table 1). Water volume should be 5 to 10 times greater than the volume of seed being treated. For example, if you were treating approximately one cup of tomato seed, the capacity of the water bath should be 5 to 10 cups. Agitation of the water during the treatment cycle will help maintain a uniform temperature in the water bath. After the prescribed amount of time, remove seed and spread on paper towels to dry. A recommended seed treatment can then be applied to protect against soilborne pathogens.

Treatment of crops other than those listed may cause serious injury to seed.

Chlorine Bleach Treatment

Soaking seed in a solution of chlorine bleach has been shown to be effective in eradicating pathogens primarily borne on the surface of the seed, such as the bacteria that cause bacterial spot, speck, and canker of tomato. It is also reported that this method can also provide some control of seed-transmitted TMV. The soaking solution should be prepared by adding 1 quart of commercial bleach (sodium hypochlorite) to 3 to 4 quarts of water. Add a drop or two of dish detergent to decrease surface tension of the solution. Soak seed in solution for 1 minute, remove and rinse thoroughly with clean water. Spread seed on paper towels to dry. Seed can be treated with a recommended fungicide to protect against soilborne pathogens.

Trisodium Phosphate (TSP)

Tomato seed can be soaked in a 10% solution of TSP for 15 minutes to eradicate seed-transmitted TMV. Remove seeds, rinse, and spread evenly on paper towels to dry. Treat with approved fungicides if needed. Most home supply and paint stores carry TSP, which is used to clean walls and surfaces prior to painting and staining. As with the other methods, it is advisable to test this process on small batches of seed at first to make sure that there are no negative effects on germination.

Table 1. Recommended temperatures and soaking times for hot-water disinfection of selected vegetable seeds.

Vegetable Crop	Water Temp. (°F)	Soaking Time (min.)
Broccoli	122	20
Brussels sprout	122	25
Cabbage	122	25
Carrot	122	20
Cauliflower	122	20
Celery	118	30
Chinese cabbage	122	20
Collards	122	20
Cucumber	122	20
Eggplant	122	25
Garlic	120	20
Kale, Kohlrabi	122	20
Lettuce	118	30
Mint	112	10
Mustard, Cress, Radish	122	15
Onion (sets)	115	60
Pepper	125	30
Rape, Rutabaga	122	20
Shallot	115	60
Spinach	122	25
Sweetpotato (roots)	115	65
Sweetpotato (cuttings, sprouts)	120	10
Tomato	122	25
Turnip	122	20

Appendix J

Sprayer Calibration

To apply the right amount of material per acre, it is necessary to know how much liquid the sprayer is delivering per acre at a given speed and pressure. The following is a fast, simple method of calibrating a sprayer for broadcast application.

Ounce Calibrations Method:

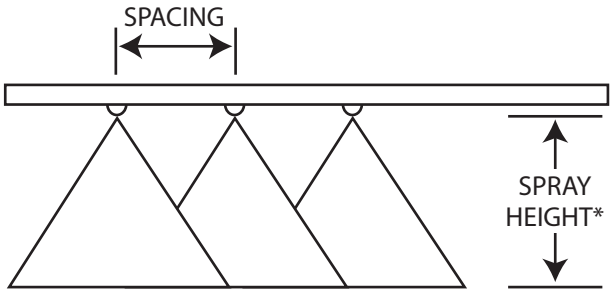
1. Using the spray calibration distance table, select the distance to catch discharge based on the row or nozzle spacing of your sprayer.
2. Measure that distance in the field to be sprayed.
3. Note the time in seconds spent to drive the measured distance at the desired throttle setting (constant speed).
4. Catch the nozzle discharge for the noted time (#3 above) in a measuring cup or other container graduated in fluid ounces.
5. The total discharge per row or nozzle spacing in fluid ounces is equal to the gallons per acre applied (at the constant speed used in #3).
6. Repeat for each nozzle or nozzle group to ensure equal distribution.

SPRAYER CALIBRATION (Distance)

Nozzle Spacing (inches)	Distance to Catch Discharge (feet)
40	102
38	107
36	113
34	120
32	127
30	136
28	146
26	157
24	170
22	185
20	204
18	227
16	255
14	291

TIP NO. (Strainer Screen Size)		Liquid Pressure in PSI	Capacity 1 Nozzle in GPM	Capacity 1 Nozzle in oz./ min.	GALLONS PER ACRE 20" SPACING				GALLONS PER ACRE 30" SPACING			
80° SERIES	110° SERIES				5 MPH	6 MPH	7 MPH	8 MPH	5 MPH	6 MPH	7 MPH	8 MPH
8001VS (100 Mesh)	11001VS (100 Mesh)	30	.09	11	5.1	4.3	3.7	3.2	3.4	2.9	2.5	2.1
		35	.09	12	5.6	4.6	4.0	3.5	3.7	3.1	2.6	2.3
		40	.10	13	5.9	5.0	4.2	3.7	4.0	3.3	2.8	2.5
		45	.11	14	6.3	5.3	4.5	3.9	4.2	3.5	3.0	2.6
		60	.12	15	7.3	6.1	5.2	4.6	4.9	4.0	3.5	3.0
80015VS (100 Mesh)	110015VS (100 Mesh)	30	.13	17	7.7	6.4	5.5	4.8	5.1	4.3	3.7	3.2
		35	.14	18	8.3	6.9	6.0	5.2	5.6	4.6	4.0	3.5
		40	.15	19	8.9	7.4	6.4	5.6	5.9	5.0	4.2	3.7
		45	.16	20	9.5	7.9	6.8	5.9	6.3	5.3	4.5	3.9
		60	.18	23	10.9	9.1	7.8	6.8	7.3	6.1	5.2	4.6
8002VS (50 Mesh)	11002VS (50 Mesh)	30	.17	22	10.3	8.6	7.4	6.4	6.9	5.7	4.9	4.3
		35	.19	24	11.1	9.3	7.9	6.9	7.4	6.2	5.3	4.6
		40	.20	26	11.9	9.9	8.5	7.4	7.9	6.6	5.7	5.0
		45	.21	27	12.6	10.5	9.0	7.9	8.4	7.0	6.0	5.3
		60	.25	32	14.6	12.1	10.4	9.1	9.7	8.1	6.9	6.1
8003VS (50 Mesh)	11003VS (50 Mesh)	30	.26	33	15.4	12.9	11.0	9.7	10.3	8.6	7.4	6.4
		35	.28	36	16.7	13.9	11.9	10.4	11.1	9.3	7.9	6.9
		40	.30	38	17.8	14.9	12.7	11.1	11.9	9.9	8.5	7.4
		45	.32	41	18.9	15.8	13.5	11.8	12.6	10.5	9.0	7.9
		60	.37	47	22	18.2	15.6	13.6	14.6	12.1	10.4	9.1
8004VS (50 Mesh)	11004VS (50 Mesh)	30	.35	45	21	17.2	14.7	12.9	13.7	11.4	9.8	8.6
		35	.37	47	22	18.5	15.9	13.9	14.8	12.3	10.6	9.3
		40	.40	51	24	19.8	17.0	14.9	15.8	13.2	11.3	9.9
		45	.42	54	25	21	18.0	15.8	16.8	14.0	12.0	10.5
		60	.49	63	29	24	21	18.2	19.4	16.2	13.9	12.1
8005VS (50 Mesh)	11005VS (50 Mesh)	30	.43	55	26	21	18.4	16.1	17.2	14.3	12.3	10.7
		35	.47	60	28	23	19.8	17.4	18.5	15.4	13.2	11.6
		40	.50	64	30	25	21	18.6	19.8	16.5	14.1	12.4
		45	.53	68	32	26	23	19.7	21	17.5	15.0	13.1
		60	.61	78	36	30	26	23	24	20	17.3	15.2
8006VS (50 Mesh)	11006VS (50 Mesh)	30	.52	67	31	26	22	19.3	21	17.2	14.7	12.9
		35	.56	72	33	28	24	21	22	18.5	15.9	13.9
		40	.60	77	36	30	25	22	24	19.8	17.0	14.9
		45	.64	82	38	32	27	24	25	21	18.0	15.8
		60	.74	95	44	36	31	27	29	24	21	18.2
8008VS (50 Mesh)	11008VS (50 Mesh)	30	.69	88	41	34	29	26	27	23	19.6	17.2
		35	.75	96	44	37	32	28	30	25	21	18.5
		40	.80	102	48	40	34	30	32	26	23	19.8
		45	.85	109	50	42	36	32	34	28	24	21
		60	.98	125	58	49	42	36	39	32	28	24

Sprayer Calibration Continued



*Adjust spray height in the field to overlap approximately 30% of each edge of pattern.

SUGGESTED MINIMUM SPRAY HEIGHT	
SPRAY ANGLE	SPRAY HEIGHT 20" SPACING
80º 110º	17-19" 10-12"

Flat Fan Spray Tips

8002VS	Stainless Steel with VisiFlo color coding
8002-HSS	Hardened Stainless Steel
8002-SS	Stainless Steel
8002	Brass

Tee Jet™ is a registered trademark of Spraying Systems Co. of Wheaton, Illinois.

Appendix K

Earliest and Latest Vegetable Crop Planting Dates in Kentucky

As every vegetable grower knows, a week earlier (or later) on the market can sometimes make the difference between a highly profitable crop and a net loss. Information in the following tables is provided as an aid to planning. Table 1 lists earliest and latest safe planting dates for various vegetable crops based on experiences of growers in eastern, central, and western Kentucky; however, these are not absolute and it is always possible for killing frosts to occur later or earlier than the range of dates provided. Frosts are greatly influenced by small variations in topography and microclimate, and growers can best judge for themselves how prone their fields are to early or late frosts.

Table 2 provides average dates for the latest frosts in spring and the earliest frosts in the fall. These dates are based on 30-year averages from the Kentucky weather stations listed. Find the nearest station location in the list and use the dates found in the same row. These dates represent a 90% probability (nine years out of 10) that the last frost (at or below 32°F) will occur on or before the date listed for "Latest Spring Frost" or a 90% probability that the first frost will occur on or after the date listed for "Earliest Fall Frost."

Use this information with caution; small differences in landscape and elevation can result in later frosts in spring and earlier frosts in the fall. Local experience will help determine the best planting dates for various crops at your location. If pushing the boundaries of these frost dates, it is recommended to have row cover on hand in case of an unexpected frost.

Table 1. Earliest and latest safe field planting dates for Eastern, Central and Western Kentucky.

Crops	Earliest Date[1]			Latest Date[1,2]		
	Eastern	Central	Western	Eastern	Central	Western
Asparagus (crowns)	Mar 20	Mar 15	Mar 10			
Beans (snap)	May 1	Apr 25	Apr 10	Jul 15	Jul 25	Aug 1
Beans (lima)	May 10	May 1	Apr 15	Jun 15	Jun 20	Jul 1
Beets	Mar 20	Mar 15	Mar 10	Aug 1	Aug 10	Aug 15
Broccoli (transplants)	Apr 5	Mar 30	Mar 25	Jul 15	Aug 1	Aug 15
B. Sprouts (transplants)	Apr 10	Apr 5	Mar 30	Jul 1	Jul 15	Aug 1
Cabbage	Apr 1	Mar 25	Mar 15	Jul 1	Jul 15	Aug 1
Carrots	Apr 1	Mar 20	Mar 10	Jul 1	Jul 15	Aug 1
Cauliflower (transplants)	Apr 10	Apr 5	Mar 30	Jul 15	Jul 20	Aug 5
Chard	Apr 1	Mar 20	Mar 15	Jun 15	Jul 15	Aug 1
Collards	Mar 15	Mar 10	Mar 1	Aug 15	Aug 20	Aug 30
Sweet Corn	May 1	Apr 20	Apr 10	Jun 15	Jul 10	Jul 20
Cucumbers	May 10	May 5	Apr 25	Jun 15	Jul 1	Jul 15
Eggplant (transplants)	May 15	May 10	May 1	Jun 1	Jun 15	Jul 1
Kale	Apr 1	Mar 20	Mar 10	Jul 15	Aug 1	Aug 15
Kohlrabi	Mar 25	Mar 20	Mar 15	Jul 15	Aug 1	Aug 15
Lettuce (leaf)	Apr 1	Mar 25	Mar 15	Aug 1	Aug 15	Sep 1
Lettuce (bibb plants)	Apr 1	Mar 25	Mar 15	Jul 15	Aug 1	Aug 15
Muskmelons	May 15	May 10	Apr 25	Jun 15	Jul 1	Jul 15
Okra	May 15	May 10	Apr 20	Jul 1	Jul 15	Aug 1
Onions (sets)	Mar 15	Mar 10	Mar 1			
Onions (transplants)	Apr 1	Mar 25	Mar 15	Jun 15	Jul 1	Jul 15
Onions (seed)	Apr 1	Mar 20	Mar 10	Jun 1	Jun 15	Jul 1
Parsley	Apr 1	Mar 20	Mar 10	Jul 15	Aug 1	Aug 15
Parsnips	Apr 1	Mar 20	Mar 10	Jun 1	Jun 15	Jul 1
Peas	Mar 15	Mar 1	Feb 20			
Peppers (transplants)	May 20	May 10	May 1	Jun 15	Jul 1	Jul 15
Potatoes	Mar 20	Mar 15	Mar 15	Jun 15	Jul 1	Jul 15
Sweetpotatoes	May 20	May 10	May 1	Jun 1	Jun 10	Jun 15
Pumpkins	May 10	May 5	Apr 25	Jun 1	Jun 15	Jul 1
Radishes	Mar 15	Mar 10	Mar 1	Sep 1	Sep 15	Oct. 1
Rhubarb (crowns)	Mar 15	Mar 10	Mar 1			
Southernpeas	May 10	May 5	Apr 20	Jun 15	Jul 1	Jul 15
Snow Peas	Mar 15	Mar 1	Feb 20	Jul 20	Aug 1	Aug 8
Spinach	Mar 10	Mar 1	Feb 15	Aug 15	Sep 1	Sep 15
Summer Squash	May 15	May 10	Apr 20	Jul 15	Aug 1	Aug 15
Tomatoes (transplants)	May 15	May 5	Apr 20	Jun 1	Jun 15	Jul 1
Turnips	Mar 15	Mar 10	Mar 1	Aug 1	Aug 10	Aug 20
Watermelons	May 15	May 5	Apr 20	Jun 15	Jul 1	Jul 15
Winter Squash	May 15	May 10	Apr 20	Jun 15	Jul 1	Jul 15

[1] Dates are for direct seeding unless otherwise indicated under "Crops" column.
[2] Based on the average time to harvest for early maturing varieties; mid-season and late-maturing varieties need to be planted 15 to 30 days earlier than latest date. Most fall-planted crops require irrigation.

Earliest and Latest Vegetable Crop Planting Dates in Kentucky Cont.

Table 2. Average frost dates in Kentucky.

Weather Station	Latest Spring Frost	Earliest Fall Frost
Eastern		
Ashland	May 21	Sep 28
Barbourville	May 8	Oct 9
Baxter	May 6	Oct 9
Grayson	May 17	Sep 28
Heidelberg	May 12	Oct 4
Hyden	May 12	Oct 4
London Corbin Airport	May 7	Oct 1
Manchester	May 17	Sep 25
Middlesboro*	May 11	Oct 4
Monticello	May 6	Oct 3
Mount Vernon	May 10	Oct 3
Somerset	May 7	Oct 2
Stearns	May 12	Sep 29
West Liberty	May 22	Sep 25
Williamsburg	May 8	Oct 5
Bluegrass		
Bardstown	May 6	Oct 3
Berea College	Apr 29	Oct 6
Carrollton Lock	May 4	Oct 8
Cincinnati/Covington	May 6	Oct 5
Covington	May 9	Oct 4
Cynthiana	May 8	Oct 6
Danville	Apr 26	Oct 13
Dix Dam	Apr 25	Oct 12
Falmouth*	May 10	Sep 24
Farmers 2 S	May 10	Sep 30
Frankfort (Lock 4)	May 3	Oct 6
Lexington (Blue Grass Airport)	Apr 28	Oct 10
Maysville Sewage Plant	May 7	Oct 7
Mount Sterling	May 5	Oct 9
Shelbyville	May 14	Sep 22
Warsaw Markland Dam	May 9	Oct 3
Williamstown	Apr 26	Oct 6

Table 2. Continued

Weather Station	Latest Spring Frost	Earliest Fall Frost
Central		
Barren River Lake	Apr 29	Oct 5
Berheim Forest	May 12	Oct 2
Bowling Green	Apr 26	Oct 8
Bradfordsville	May 10	Sep 30
Cambellsville*	Apr 30	Oct 5
Glasgow	Apr 28	Oct 6
Greensburg	May 2	Oct 6
Hodgenville-Lincoln	May 2	Oct 6
Jamestown	Apr 28	Oct 9
Leitchfield	May 6	Oct 3
Louisville Airport	Apr 21	Oct 15
Mammoth Cave	May 10	Oct 1
Nolin River Lake	May 13	Sep 29
Rough River Lake	May 11	Sep 26
Scottsville	Apr 19	Oct 11
Summer Shade	May 6	Oct 4
Western		
Bardwell	Apr 21	Oct 3
Beaver Dam	Apr 28	Oct 3
Gilbertsville	Apr 17	Oct 16
Golden Pond	Apr 18	Oct 11
Henderson	Apr 20	Oct 7
Hopkinsville*	Apr 22	Oct 4
Lovelaceville	Apr 28	Oct 3
Madisonville	Apr 24	Oct 6
Mayfield	Apr 25	Oct 7
Murray	Apr 17	Oct 10
Owensboro*	Apr 23	Oct 5
Paducah (Barkley Regional Airport)	Apr 21	Oct 9
Princeton	Apr 25	Oct 6
Rochester Ferry	Apr 24	Oct 5
Russellville	Apr 26	Oct 6

**Weather station had missing data. Dates were estimated using data from surrounding stations.*

Appendix L

Relative Efficacy of Insecticides Against Common Arthropod Pests of Vegetable Crops in the Southeastern United States

Not all insecticides listed below are registered on all vegetable crops—check the label before applying to a specific crop.

Chemical class (IRAC)	Common name	Example Product	Greenhouse use	Flea beetles	Colorado potato beetle*	Cucumber beetles	Corn earworm*	European corn borer	Fall armyworm	Cabbage looper	Imported cabbageworm	Diamondback moth*	Squash vine borer	Beet armyworm*	Stink/Harlequin bugs	Squash bug	Aphids*	Thrips	Western flower thrips	Maggots	Whiteflies*	Cutworms	Wireworms	White grubs	Spider mites*	Broad mite
1A	carbaryl	Sevin		3	1	2	1	2	1	1	2	1	1	x	x	x	x	1	x	x	x	1	x	x	x	x
	methomyl	Lannate		1	x	x	2	2	2	2	2	2	x	1	2	2	1	3	2	x	x	x	x	x	x	x
1B	malathion	Malathion		2	1	2	1	1	1	1	2	1	1	x	1	1	1	1	x	1	x	1	x	x	x	x
	acephate	Orthene	No	x	x	x	1	3	2	1	2	x	x	x	x	x	2	2	x	x	x	2	x	x	x	x
	diazinon	Diazinon	No	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	1	2	1	x	x
	dimethoate	Dimethoate		2	x	1	x	x	x	x	x	x	x	x	2	1	3	3	2	x	x	x	x	x	x	x
3	permethrin	Pounce		2	1	2	2	2	1	2	3	1	3	x	1	2	1	1	x	x	x	2	x	x	x	x
	alphacypermethrin	Fastac		2	1	2	2	2	2	2	3	1	3	x	2	2	1	1	x	x	x	2	x	x	x	x
	zeta cypermethrin	Mustang Maxx		3	1	3	2	3	2	2	3	1	3	x	2	3	1	1	x	x	x	3	x	x	x	x
	beta cyfluthrin	Baythroid		3	1	3	2	3	1	2	3	1	3	x	2	3	1	1	x	x	x	3	x	x	x	x
	lambda cyhalothrin	Warrior		3	1	3	2	3	2	2	3	1	3	x	2	3	1	1	x	x	x	3	x	x	1	x
	esfanvalerate	Asana XL		2	2	2	2	2	1	2	3	1	2	x	1	2	1	1	x	x	x	2	x	x	x	x
	gamma cyhalothrin	Proaxis		3	1	3	2	3	2	2	3	1	3	x	3	3	1	1	x	x	x	3	x	x	x	x
	fenpropathrin	Danitol		2	x	2	2	2	1	1	3	1	2	x	3	3	1	1	x	x	X	2	x	x	1	x
	bifenthrin	Brigade/Capture		3	1	3	2	2	1	1	3	1	3	x	3	3	1	1	x	1	x	3	2	1	1	x
4A	imidacloprid	Admire		1	2	3	x	x	x	x	x	x	x	x	1	2	3	2	x	2	2	x	1	2	x	x
	acetamiprid	Assail		2	3	2	x	x	x	x	x	x	1	x	1	2	3	2	x	x	2	x	x	x	x	x
	clothianidin	Belay		3	3	2	x	x	x	x	x	x	x	x	2	2	2	x	x	2	1	x	1	2	x	x
	thiamethoxam	Platinum/Actara	No	3	2	2	x	x	x	x	x	x	x	x	2	2	3	1	x	2	2	x	1	1	x	x
	dinotefuran	Venom/Scorpion		3	3	2	x	x	x	x	x	x	x	x	3	3	1	2	x	x	2	x	x	x	x	x
4C	sulfoxaflor	Closer/ Transfrom	No	x	x	x	x	x	x	x	x	x	x	x	1	x	3	x	x	x	1	x	x	x	x	x
4D	flupradifurone	Sivanto Prime	No	x	x	x	x	x	x	x	x	x	x	x	x	2	3	x	x	x	3	x	x	x	x	x
5	spinosad	Blackhawk/Entrust	No	x	3	x	2	2	2	2	3	2	2	2	x	x	x	2	2	x	x	1	x	x	x	x
	spinetoram	Radiant	No	x	3	x	3	3	2	2	3	2	2	2	x	x	x	3	2	x	x	1	x	x	x	x
6	emamectin benzoate	Proclaim	No	x	x	x	2	2	2	3	3	3	2	3	x	x	x	x	x	x	x	1	x	x	1	x
	abamectin	AgriMek		x	3	x	x	x	x	x	x	x	x	x	x	x	x	2	1	x	x	x	x	x	3	3
7C	pyriproxyfen	Knack/Distance		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x	x
9a	pyrifluquinazon	PQZ		x	x	x	x	x	x	x	x	x	x	x	x	x	3	x	x	x	2	x	x	x	x	x
9B	pymetrozine	Fulfill		x	x	x	x	x	x	x	x	x	x	x	x	x	3	x	x	x	1	x	x	x	x	x
10B	etoxazole	Zeal		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x
11A	Bt	Dipel, various		x	x	x	1	1	1	2	3	1	1	1	x	x	x	x	x	x	x	x	x	x	x	x
		XenTari		x	x	x	1	1	1	2	2	2	1	2	x	x	x	x	x	x	x	x	x	x	x	x
15	novaluron	Rimon		x	3	x	3	3	3	2	3	1	2	3	1	1	x	2	2	x	1	x	x	x	x	x
16	buprofezin	Courier		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x	x
18	methoxyfenozide	Intrepid		x	x	x	2	2	3	3	3	1	2	3	x	x	x	x	x	x	x	x	x	x	x	x
20B	acequinocyl	Kanemite		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	3	3
20D	bifenazate	Acramite/Floramite		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	3	x
21A	fenazaquin	Magister		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	1	x	x	x	2	2
	fenpyroximate	Portal		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	1	x	x	x	2	2
	tolfenpyrad	Torac		2	x	x	1	1	1	1	2	x	x	1	x	x	2	2	1	x	1	x	x	x	x	2
22A	Indoxacarb	Avaunt eVo		1	2	1	3	2	2	3	3	2	2	3	x	x	x	x	x	x	x	1	x	x	x	x
23	spiromesifen	Oberon		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	1	x	x	x	2	2
	spirotetramat	Movento	No	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	1	x	x	x	1	x
25	cyflumetofen	Nealta	No	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x
28	rynaxypyr	Coragen		x	3	x	3	3	3	3	3	3	2	3	x	x	x	1	x	x	3	1	x	x	x	x
	cyantraniliprole	Exirel/Verimark	No	2	3	x	3	3	3	3	3	3	2	3	x	x	2	1	1	2	3	x	x	x	x	x
	cyclaniliprole	Harvanta	No	1	3	x	3	3	3	2	3	3	2	3	x	x	x	1	1	x	1	x	x	x	X	x
29	flonicamid	Beleaf		x	x	x	x	x	x	x	x	x	x	x	x	x	3	2	3	x	1	x	x	x	x	x

** Resistance may exist in some areas | x = Ineffective or insufficient data | 1 = Somewhat effective | 2 = Effective | 3 = Very Effective*

Notes

Notes

Notes

Pesticide Emergency Telephone Numbers

Pesticide Spills

If you have a pesticide spill and need information on how to handle this type of emergency, call:

911

and

Kentucky Environmental Response Team

(800) 928-2380

or

(502) 564-2380

Pesticide Exposures

If someone has been exposed to a particular pesticide, provide the physician with the following emergency number, which is designed to provide pharmacological information on pesticides to health professionals.

Kentucky Regional Poison Center

(800) 222-1222

In Metro Louisville, call:

(502) 589-8222

National Pesticide Information Center

(800) 858-7378

Provides general and scientific information on pesticides. This center operates seven days a week from 6:30 am to 4:30 pm Pacific Time excluding some holidays.

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Lexington, KY 40506 Revised 01-2024

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NC STATE EXTENSION

Growing Small Farms

Home » **Season Extension: Introduction and Basic Principles**

Season Extension: Introduction and Basic Principles

Find this page at:
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> en Español / em Português

Debbie Roos
North Carolina Cooperative Extension, Chatham County Center

Doug Jones
Common Ground Ecovillage

What exactly is season extension?

In agriculture, season extension refers to anything that allows a crop to be cultivated beyond its normal outdoor growing season.

Advantages

- Possible year-round income
- Retention of old customers
- Gain in new customers
- Higher prices
- Higher yields
- Better quality

- Extended employment for workers

Disadvantages

- No break in yearly work schedule
- Increased management demands
- Higher production costs
- Plastic disposal problems

How does season extension contribute to sustainability?

"…to make a real difference in creating a local food system, local growers need to be able to continue supplying "fresh" food through the winter months…[and] to do that without markedly increasing our expenses or our consumption of non-renewable resources".

– Eliot Coleman, The New Organic Grower

Thermodynamics and Properties of Plants

We can extend the growing and harvest season for crops through techniques that evolve from two primary strategic goals:

1. Protecting crops from damage from extremes of heat or cold
2. Enhancing the growth of crops for quicker maturity and higher quality under adverse weather conditions

Often one technique will affect more than one strategy. For example, a raised bed will dry faster and warm up sooner in spring, but will therefore require more attention to irrigation needs, and may develop higher-than-desirable soil temperatures sooner than flat ground when summer arrives. It can also cool faster than flat ground. Another example: A row cover may protect a crop from a frost, but can also prevent the crop from developing as much hardiness as an uncovered crop, due to the artificial mild climate under the cover.

Growers are much more likely to succeed in their efforts to extend the growing season for crops if they understand some basic principles about heat and cold, about how plants respond to thermal changes, and how various landscape features and protective materials influence the thermal environment of plants.

Controlling the flow of heat

- The ground is a huge reservoir of heat. It's the heat radiating from the soil that protects crops at night when you cover them, or protects the lower part of plants that have a good canopy of leaves. As the ground gets colder in late fall, it radiates less heat. Thus the leaf canopy or added row covers will give less protection as the ground cools. The reverse is true as the soil temperature increases in spring. Wet ground conducts and radiates more heat than dry ground.

- Lighter, sandier soils and any soil in a raised bed will dry out, warm up, and become workable earlier in the spring. Adding organic matter to clay soils can improve drainage; this will also darken any soil so it will absorb more heat. Dark mulches, such as black plastic, also raise soil temps. Mulches will insulate the ground and allow less heat out at night; thus crops will be colder on mulched ground.

- Clouds form a "blanket" that slows radiant heat loss from the earth. Temperatures can drop as much as 5-10° F within an hour after the sky clears at night. The arrival of cloud cover will often raise temperatures and save crops on a frosty night.

- Water can store a lot of heat and can give it up relatively quickly. This enables overhead irrigation to protect a crop from frost. It also creates warmer microclimates near ponds or other bodies of water.

- Water also absorbs heat quickly, and evaporating water removes heat from its environment. Thus, overhead irrigation on a hot day can cool heat-sensitive crops or aid germination of heat sensitive seeds.

- Land sloping to the south will stay warmer in the late fall and warm up sooner in the early spring. Land sloping east will warm sooner in the morning; to the west it stays warmer in the evening.

- Cold air is heavier than warm air, and will slide down slopes to settle in flat areas or hollows, often referred to as "frost pockets". On a calm night, the warmest "microclimate" in a given area will often be near the top of a slope. Objects in a landscape, such as buildings or created windbreaks, can influence the movement of cold air. Windbreaks uphill from a crop can protect from frost; downhill from a crop may cause trapping of cold air. A forest surrounding a smaller, level field on several sides may also keep cold air from reaching the crops.

- Windbreaks, such as buildings, hedges, fencerows, or woods, can influence microclimates in other ways. They can create a useful "microclimate", where solar gain can accumulate in daytime; wind can stress plants by accelerating evaporation

from leaves; it can also push cold air deeper into the canopy of the crop or through a row cover. The “wind chill factor” means: moving air extracts heat from objects faster than still air.

- Remember: Weather forecasts are usually for urban areas; temperatures on clear nights can be as much as 10 degrees lower in rural frost pockets than what is stated in the media for a general local area.

Hardiness: Which Crops Have How Much, and Under What Conditions?

- If the weather gets colder gradually, plants will develop hardiness, and be less damaged by extreme cold. If extreme cold immediately follows a warm spell, it will do much more damage to most crops.

- Moderate wind also helps to harden crops, both in the field and in seed flats. “Soft” transplants, freshly transplanted to the field, are more vulnerable to frost damage than hardened plants.

- Higher nitrogen levels will keep plants soft, less hardy. Various stresses and health conditions can also lessen hardiness.

- Each crop, when thoroughly hardened, has a typical threshold temperature, below which it will usually be damaged. Within each crop, varieties will vary in their hardiness, hence the range of temperatures given in the following table. Consult seed catalog variety descriptions for mention of degree of hardiness. The table below is based on Doug Jones’ personal experience.

Threshold Damage Temperatures for Common Crops

TENDER CROPS (crops originally from the tropics): All are damaged at 31-32° F. These include all the nightshades – tomatoes, peppers, etc. (young potatoes can recover from moderate frost), cucurbits (squashes, cukes, melons, etc), beans, basil, sweet potatoes, and corn (can also recover).

COOL SEASON CROPS: Most crops below will survive at temperatures lower than the indicated range. If winter survival is the main goal, some damage is acceptable; the plants will usually recover as the weather warms up.

VERY HARDY
Leeks (5-20° F)
Parsnips (28° F, tops 15° F, roots 0° F)

Spinach (8-12°)

HARDY

Cabbage (12-20° F)
Broccoli (18-22° F)
Brussels Sprouts (15-20° F)
Rutabaga (10-15° F)
Kale (10-15° F)
Mustard (10-15° F)

SEMI-HARDY

Lettuce (20-25° F)
Cauliflower (25-28° F)
Carrot (tops 10° F, roots 30° F)
Beets, Chard (15-25° F)
Peas (18-25° F, blossoms 30° F)

Slow-Growing Cool Season Crops – a Special Challenge in the Piedmont

In the Piedmont, we have two seasons of moderate weather enjoyed by cool weather crops (60-75° days): spring and fall. These seasons are often less than 60 days long. The quick-maturing crops are relatively easy to fit into this window: lettuce, spinach, mustard greens, radishes, spring peas, fall carrots. Using transplants helps to fit the cole crops into spring and fall, though the fall seedlings need to be started in a shaded location, and the spring crop in a greenhouse or cold frame. Very slow crops, like parsnips, Brussels sprouts, and celery are more difficult. Row covers can help to get these crops started extra early in spring, so they can finish before hot weather degrades them. Covers can help the fall crop mature without damage.

Temperature Extremes Affecting Germination and Seedling Vigor

One limitation of early spring planting is the negative effect of cold soil on germination. **Seedlings that emerge slowly are much more vulnerable** to attack by soil pathogens. Clear plastic laid directly on a seedbed can help seeds germinate quickly, provided the soil doesn't overheat.

Conversely, hot soil inhibits germination of some fall crops, particularly spinach, lettuce, parsnips, beets. Use mulches, shading, and/or micro-sprinklers to cool the soil and crop.

Days required for vegetable seedling emergence at various soil temperatures for seeds planted ½ inch deep

	Soil Temperature (° F)					
Crop	41	50	60	68	77	86
Cool Season						
Broccoli	28	20	10	7	5	4
Cabbage	24	15	9	6	5	4
Cauliflower	30	20	10	6	5	5
Onion	31	13	7	5	4	4
Pea	36	14	9	8	6	6
Spinach	23	12	7	6	5	6
Warm Season						
Snap Beans	NG	NG	16	11	8	6
Eggplant	–	–	27	13	8	5
Muskmelon	–	–	NG	8	4	3
Pepper	NG	NG	25	13	8	8
Sweet Corn	NG	22	12	7	4	4
Tomato	NG	43	14	8	6	6

NG = No Germination; – = Not Tested
Source: California Agricultural Extension Leaflet

Cultural Practices for Season Extension

Cultural Practices for Modifying Micro-climate

There are lots of things you can do to modify the crop microclimate that do not involve covers or structures. Some of these strategies require long-term planning.

Site Selection

Land with a south-facing slope will stay warmer in the late fall and warm up sooner in the early spring. A site at the top of the slope, with unimpeded air drainage down the hill, would be ideal for maximizing season extension.

Soil and Moisture Management

Adding organic matter, tillage, raised beds, improve drainage

Cultivar Selection

- Cultivar selection is an important strategy for achieving season extension. The number of days from planting to maturity varies from cultivar to cultivar, and some cultivars germinate better in cool soil than others.
- Staggered planting dates can be combined with the use of cultivars spanning a range of maturity dates to greatly extend the harvest season for any one crop.
- Heat-tolerant varieties can help extend the season of certain crops.
- See ATTRA publication Scheduling Vegetable Plantings for Continuous Harvest

Transplants

Use of transplants is a key season extension technique. They can provide a 3-4 week head start on the season.

Irrigation

- Increasing or decreasing soil water content can enable tillage operations, prevent waterlogging of the root zone and/or aid germination.
- Overhead irrigation can be used to protect crops from frost. Micro-sprinklers can be used to cool them.

Windbreaks

- Use of windbreaks can result in increased yield and earlier crop production by providing wind protection. Young plants are most susceptible to wind damage and “sand blasting”. Rye strips between rows can provide protection from wind and wind-borne sand. Windbreaks can improve early plant growth and earlier

crop production, particularly with melons, cucumbers, squash, peppers, eggplant, tomatoes, and okra.

- **The major benefit of a windbreak is improved use of moisture**. Reducing the wind speed reaching the crop reduces both the direct evaporation from the soil and the moisture transpired from the crop. This moisture advantage also improves conditions for seed germination. Seeds germinate more rapidly and young plants put down roots more quickly. Improved moisture conditions continue to enhance crop growth and development throughout the growing season.

- **The type and height of the windbreak determine its effectiveness**. Windbreaks can be living or non-living. Rye strips are suggested for intensive vegetable production based on economics. In general, the windbreak has a significant effect on the crop at a distance of 8 times the height of the windbreak. A rye strip 3 feet tall will protect vegetables up to 24 feet away. The windbreak should be planted perpendicular to the prevailing wind direction. Rye strips should be planted from September through October to obtain good plant establishment and to provide adequate time for plant growth prior to beginning the next production season.

Fabrics and Structures for Season Extension

Plastic Mulch

- Plastic mulches have been used commercially for the production of vegetables since the early 1960s. Plastic mulches provide many positive advantages for the user, such as increased yields, earlier maturing crops, crops of higher quality, enhanced insect management, and weed control. They also allow other components, such as drip irrigation, to achieve maximum efficiency. Although a variety of vegetables can be grown successfully using plastic mulches, muskmelons, tomatoes, peppers, cucumbers, squash, eggplant, watermelons, and okra have shown the most significant responses. Production of strawberries and cut flowers is also greatly improved by the use of plastic mulch.

- Plastic mulches directly impact the microclimate around the plant by modifying the radiation budget (absorbitivity vs. reflectivity) of the surface and decreasing the soil water loss. The **color** of a mulch largely **determines its energy-radiating behavior** and its influence on the microclimate around a vegetable plant. Color affects the surface temperature of the mulch and the underlying soil temperature. Another important factor is the **degree of contact between the**

mulch and soil or by not being taut, often quantified as a thermal contact resistance, will greatly influence the performance of a mulch. If an air space is created between the plastic mulch and the soil by a rough soil surface, soil warming can be less effective than would be expected from a particular mulch.

- **Black plastic mulch** – the predominant color used in vegetable production is an opaque blackbody absorber and radiator. Much of the solar energy absorbed by black plastic mulch is lost to the atmosphere through radiation and forced convection. The efficiency with which black mulch increases soil temperature can be improved by optimizing conditions for transferring heat from the mulch to the soil. Because thermal conductivity of the soil is high relative to that of air, much of the energy absorbed by black plastic can be transferred to the soil by conduction if contact is good between the plastic mulch and the soil surface. Soil temperatures under black plastic mulch during the daytime are generally 5° F higher at a 2-inch depth and 3° F higher at a 4-inch depth compared to those of bare soil.

- **Clear plastic mulch** – absorbs little solar radiation but transmits 85% to 95%, with relative transmission depending on the thickness and degree of opacity of the polyethylene. The undersurface of clear plastic mulch usually is covered with condensed water droplets. This water is transparent to incoming shortwave radiation but is opaque to outgoing longwave infrared radiation, so much of the heat lost to the atmosphere from a bare soil by infrared radiation is retained by clear plastic mulch. Thus, daytime soil temperatures under clear plastic mulch are generally 8 to 14° F higher at a 2-inch depth and 6 to 9° F higher at a 4-inch depth compared to those of bare soil. Clear plastic mulches generally are used in the cooler regions of the United States, such as the New England states. Weeds can be a big problem under clear mulch.

- **White, white-on-black, or silver reflecting mulch** – can result in a slight decrease in soil temperature (-2° F at 1-inch depth or -0.7° F at a 4-inch depth) compared to bare soil, because they reflect back into the plant canopy most of the incoming solar radiation. These mulches can be used to establish a crop when soil temperatures are high and any reduction in soil temperatures is beneficial.

- **Infrared-transmitting mulch** – These mulches provide the weed control properties of black mulch but are intermediate between black and clear mulch in terms of increasing soil temperature. The color of these mulches can be blue-green or brown. These mulches warm up the soil like clear mulch but without the accompanying weed problem.

- **Red mulch** – performs like black mulch, warming the soil, controlling weeds, and conserving moisture, with one important difference. In Pennsylvania experiments, tomato crops responded with an average 12% increase in marketable fruit yield over a 3-year period. There appears to be a reduction in the incidence of early blight in plants grown on red mulch, compared with plants grown on black mulch. When environmental conditions for plant growth are ideal, tomato response to red mulch is minimal. Other crops that may respond with higher yields include eggplant, peppers, melons, and strawberries.

Biodegradable mulch

- **Biodegradable plastics** are made with starches from plants such as corn, wheat, and potatoes. They are broken down by microbes. Biodegradable plastics currently on the market are more expensive than traditional plastics, but the lower price of traditional plastics does not reflect their true environmental cost. Field trials in Australia using biodegradable mulch on tomato and pepper crops have shown it performs just as well as polyethylene film, and it can simply be plowed into the ground after harvest. Researchers with Cornell University also found that biodegradable mulches supported good yields, but the films they used are not yet commercially available in the U.S. Bio-Film is the first gardening film for the U.S. market. Made from cornstarch and other renewable resources, it is 100% biodegradable. Bio-Film is available from Dirt Works in Vermont.

- **Paper mulch** can provide benefits similar to plastic and is also biodegradable. An innovative group in Virginia carried out on-farm experiments to explore alternatives to plastic. They compared soil temperatures and tomato growth using various mulches, including black plastic, Planters Paper, and recycled kraft paper. Plastic, paper, and organic mulches all improved total yields of tomatoes grown in the trials, when compared with tomatoes grown on bare soil.

- **Recycled kraft paper** is available in large rolls at low cost. Participants in the experiment were concerned that it would break down too quickly. To retard degradation, they oiled the paper. This resulted in rather transparent mulch and, as with clear plastic, soil temperatures were higher than under black plastic. Weeds also grew well under the transparent mulch. To reduce weed growth and to keep the soil from becoming too hot, the experimenters put hay over the oiled paper several weeks after it was laid.

- **Planters Paper** is a commercially available paper mulch designed as an alternative to plastic. It comprises most of the benefits of black plastic film and has other advantages. It is porous to water. Left in the soil, or tilled in after the

growing season, it will degrade. Tomatoes grown with this mulch showed yields and earliness similar to tomatoes grown in black polyethylene mulch, even though the latter resulted in slightly higher soil temperatures. Planters Paper, however, is considerably more expensive than black plastic. It does not have the stretchability of plastic, and it tends to degrade prematurely along the edges where it is secured with a layer of soil. The paper is then subject to being lifted by the wind. Rebar, old pipe, or stones—rather than soil—can be used to secure the edges.

Source: ATTRA Season Extension Techniques for Market Gardeners

Row Covers

Two main **types of row covers**:

1. **floating row covers** – lie directly over the crop and may cover multiple rows

1. **Hoop-supported row covers** – sometimes referred to as low tunnels, they generally cover a single row

There are also **two basic types of row cover materials**:

1. clear polyethylene
2. spunbonded polyester or polypropylene

All of these are available in varying thicknesses, weights, widths, and lengths.

- Crop distinctions such as temperature sensitivity, pollination methods, and growth habit dictate the type of row cover that is best to use.

- Spunbonded covers are comprised of a thin mesh of white synthetic fibers which entrap heat and serve as a barrier to wind, insects, and varmints. Water from rain or overhead irrigation freely passes through. The weight of these covers ranges from 0.3 to about 2.0 oz/sq yd. The **lightest covers** are used primarily for **insect exclusion** while the **heaviest** of the covers are used for **frost protection.** The most common **medium weights** are 0.5 to 1.25 oz/sq yd and are best for **season extension** for such crops as melons, cucumbers, squash, lettuces, peas, carrots, radishes, potatoes, sweet corn, strawberries, and cut flowers. With covers under 0.5 oz there is minimal heat retention at night; and over 1.75 oz, there is a significant reduction in light transmission. The heavy

covers are used for nighttime frost protection only since they do not transmit sufficient light for optimum crop growth.

- Spunbonded row covers in the 0.5 to 1.25 oz range provide 2-4° F frost protection in the spring. In the fall, there is more protection because there is a larger reservoir of heat in the soil in the fall than in the spring.

Floating row covers

- Floating covers require much less installation labor than hoop supported covers. The wider and longer the covers, the less labor required per unit area since only the edges are secured. These covers vary in width from 3 to 60 feet and up to over 2,000 feet long. Even though most crops can be grown without damage under floating covers, tomatoes and pepper are an exception. If the spunbonded material is not supported with wire hoops for these crops, flapping of the cover in the wind will damage the growing points of young plants. Also, with summer squash under windy conditions, many of the leaves might be broken by the cover. For these three crops, a series of strategically placed wire hoops will prevent crop damage.

- Weed control can be a significant problem under row covers unless they are used in combination with plastic or some other type of mulch.

Hoop-supported row covers

- Hoop-supported row covers are often called low tunnels. They offer many of the same benefits as floating row covers, but are not permeable to air or water and are more labor-intensive. There are several types of low tunnels. Slitted row covers have pre-cut slits that provide a way for excessive hot air to escape. At night the slits remain closed, reducing the rate of convective heat loss and helping to maintain higher temperatures inside the tunnel. Punched row covers have small holes punched about 4 inches apart to ventilate hot air. The punched covers trap more heat than the slitted tunnels. They are best for northern areas and must be managed carefully to avoid overheating crops on bright days. They are useful for peppers, tomatoes, eggplant, most cucurbits, and other warm-season crops that grow upright.

Additional Observations by Doug Jones:

- In the protected, wind-free, slightly warmer environment under the cover, crops will grow faster during cold weather. Ironically, this effect also prevents plants

from developing as much hardiness as equivalent crops with no protection! To deal with this, I add a second cover when extreme cold is forecast.

- In the Piedmont, many cool-season crops can be brought through the winter under an adequate thickness of fabric (medium weight fabric: add a second layer). Crops actually grow a little during winter warm spells.

- High (hoophouse) or low tunnels with a single layer of clear plastic get much warmer on sunny winter days than fabric covered beds, so crops will grow faster. But it gets about as cold at night in the hoop house as under the fabric covers. In the coldest weather I like to add a row cover to beds of semi-hardy crops inside the hoophouse. Clear plastic must be ventilated on calm, sunny days when ambient temperatures are above 50-60° F. Otherwise, the crop will be overheated.

- Plant leaves that touch the fabric usually get more damaged from extreme cold, and from strong winds whipping the cover back and forth. A tunnel structure of heavy (9 gauge) wire hoops will help to keep the fabric from touching the leaves of the crop. Concrete block wire ("ladder wire") makes a more stable tunnel structure. It's important to stretch the fabric very tight end-to-end, and use lots of pins, soil, or rocks to keep big winds from blowing your covers into the trees. Red plastic "Repins™" are very effective for pinning, as well as easy to pull up for access to the crop.

- Wire hoops are not sufficient to prevent heavy snow from collapsing the cover. Sometimes I just take the cover off when a big snow is forecast, and actually get less damage than under the collapsed tunnels. Powdery snow itself is a good insulator.

High Tunnels

- A high tunnel, or hoophouse, is basically an arched or hoop-shaped frame covered with clear plastic and high enough to stand in or drive a tractor through. Traditional high tunnels are completely solar-heated, without electricity for automated ventilation or heating systems.

- High tunnels have been used for many years throughout Europe, Asia, and the Middle East and they are rapidly gaining in popularity here. Several universities are now conducting high tunnel research.

Benefits of high tunnels:

- Crops grown in high tunnels tend to be cleaner and of higher quality than crops grown in the field.
- Crops grown in high tunnels can hit the market early when prices are higher and help to capture loyal customers for the entire season.
- High tunnels allow certain crops to be grown throughout the winter, providing a continuous supply to markets the entire year.
- High tunnels can prevent or slow the spread of certain diseases.
- .The most critical components of a hoop house for strength are the end walls.
- Crops that have been grown in high tunnels include specialty cut flowers, lettuce and other greens, carrots, tomatoes, peppers, squash, melons, raspberries, strawberries, blueberries, and cherries. Although high tunnels provide a measure of protection from low temperatures, they are not frost protection systems in the same sense that greenhouses are. On average, tunnels permit planting about three weeks earlier than outdoor planting of warm season crops. They also can extend the season for about a month in the fall.
- Hoophouses are not difficult to build. The most common design uses galvanized metal bows attached to metal posts driven into the ground 4 feet apart—a traditional quonset style structure. Strength is important. Heavy-gauge galvanized steel pipe is best for hoops. Setting the hoops four feet rather than any further apart is also recommended. Growers in snowy climates might choose a peaked-roof structure instead of the quonset style.
- The most economical covering is 6-mil greenhouse grade, UV-treated polyethylene, which should last three to five years. Do not use plastic that is not UV-treated—"It will fall apart after half a season". Some growers use a double layer of plastic.
- Roll-up sides used on many high tunnels provide a simple and effective way to manage ventilation and control temperature. The edge of the plastic is taped to a one-inch pipe that runs the length of the tunnel. A sliding "T" handle is attached to the end of the pipe so that the plastic can be rolled up as high as the hip board. Ventilation is controlled by rolling up the sides to dispel the heat. Depending on temperature and wind factors, the two sides may be rolled up to different heights.
- Temperature management using the roll-up sides is critical. On sunny mornings, the sides must be rolled up to prevent a rapid rise in temperature. Tomato blossoms, as mentioned earlier, will be damaged when temperatures go above 86° F for a few hours. Even on cloudy days, rolling up the sides provides ventilation to help reduce humidity that could lead to disease problems. The sides should be rolled down in the evening until night temperatures reach 65° F. A maximum/minimum thermometer is a great aid in keeping tabs on temperature.

- Twenty feet by 96 feet is a size commonly used by market growers. This size allows efficient heating and cooling, efficient growing space, and adequate natural ventilation.
- Alison and Paul Wiediger of Au Naturel Farm in Kentucky also use a commercially available 20- by 96-foot high tunnel, in addition to two 21-by 60-foot tunnels. They think there is value in building as large a structure as is practical. They also find that plants close to the walls do not grow as well as the plants further from them. The larger the frame, the larger the percentage of effective growing area. And most growers want more, rather than less, space at the end of one growing season.
- *Most of the growing in this tunnel will be in spring, fall, and winter when outside temperatures are cooler/colder. We believe that both the earth and the air within the tunnel act as heat sinks when the sun shines. At night, they give up that heat, and keep the plants safe. The smaller the structure, the smaller that temperature "flywheel" is, and the cooler the inside temperatures will be.*

- The Wiedigers use a double layer of 6-mil, 4-year poly to cover their tunnels. A small fan blows air between the two layers to create an insulating barrier against the cold. Construction and management details can be found in their manual, Walking to Spring: Using High Tunnels to Grow Produce 52 Weeks a Year (See Resources handout).

Source: ATTRA Season Extension Techniques for Market Gardeners

- Eliot Coleman popularized the concept of the **mobile** high tunnel in the U.S. The tunnels sit on railroad wheels and roll on wooden rails so they can be moved from one site to another. For example, the tunnel might be used to start a lettuce crop, and once the spring warmed up enough for the lettuce to thrive outdoors, the tunnel is moved to the second site where tomatoes are planted. Coleman's book Four-Season Harvest provides details on the mobile tunnel model.

Haygrove Multibay Tunnel Systems

- With Haygrove tunnels, innovative growers are literally covering their fields to protect high-value crops from early and late frost, heavy rain, wind, hail, and disease. The frames also provide support for shade cloth and bird netting. The British company Haygrove was started in 1988 with a little more than two acres of strawberries in hoophouses. By 2002, Haygrove had expanded to nearly 250 acres of soft fruits, including strawberries, blackberries, red currants, and cherries, grown under plastic in England and eastern Europe. They also came up with a new design for multibay tunnels and sold 3,000 acres of tunnels throughout Europe.

- Haygrove tunnels are now being distributed and used in the U.S. Haygrove sells tunnels from 18 to 28 feet wide per bay, with a three bay minimum. There are no walls between bays. The total length and width can be whatever the grower desires. Company representative Ralph Cramer in Lancaster County, Pennsylvania, says he has seen tunnels as short as 65 feet and as long as 1,100 feet. They have been used to cover from 1/3 acre to 100 acres (of blueberries in California). Unlike greenhouses, Haygrove tunnels don't need to be built on flat ground, but can be built on slopes. Cramer says advantages of the systems include lower cost and better ventilation. One acre of Haygrove tunnels costs about 55 cents per square foot, or about $24,000.

Local Example of Haygrove Tunnel System: Peregrine Farm

- Locally, Alex and Betsy Hitt of Peregrine Farm purchased a half an acre (two ¼ acre blocks) of Haygrove tunnels and first used them for the 2004 growing season. They had actually gotten a quote before the 2003 season began and the price scared them so they walked away. But then the summer of 2003 yielded a horrible tomato crop due to all the rain and disease so they decided to go for it. They had seen the Haygroves being used for cut flower production in California and Pennsylvania. They wanted them mainly as "dry houses" to keep the tomatoes dry and also for certain flowers that don't like their blooms getting wet (lisianthus, poppies, campanula, delphinium, etc.). Alex and Betsy already had 6 mobile high tunnels that worked great for tomatoes but they wanted something that could be moved with the rotation, cover lots of ground, and be well-suited for cover crops.

- They contacted Ralph Cramer of Cramer's Posie Patch, the east coast distributor for Haygrove. They ordered two ¼ acre blocks because that was the size of their rotation plots. Each bay is 24 feet wide. The Haygrove tunnels are shipped over from England. It takes about 8 weeks. The shipping cost alone is $4,000, whether the cargo container is full or not. If growers did a cooperative purchase they could reduce shipping costs. The total cost, including shipping, was $0.85/square foot. The plastic is supposed to last for at least two years; Alex will get at least three years.

- Construction of Haygroves: You have to be prepared for the delivery. You have to unload everything within two hours or you get charged Alex received over 5 tons of stuff! The roll of plastic itself weighed one ton. Need to have appropriate equipment ready for off-loading. The Hitts constructed the tunnels in October and covered them with plastic the following April. Haygrove sends someone to advise you on construction. They won't do any of the actual work but they are there to tell you how to do it. The Hitt's Haygrove rep spent an entire day with them and showed them how to lay out the field. It took two people 80 hours total to construct ½ acre of Haygroves. It took 4 people an additional hour to cover each bay in plastic.

- The Hitts use one ¼ acre block for cut flowers and one for heirloom tomatoes.|

Advantages of Haygroves

- Disease protection – Alex has a mysterious strain of anthracnose disease that attacks his tomatoes. This disease has even left our plant pathologists stumped. Under the Haygroves, the disease comes 3-4 weeks later, so instead of 5 weeks of production, he gets 8-9 weeks, and a 35% increase in income. At this rate, it will take three years to pay off the tunnels. They are still trying to work out which crops are best suited for the Haygroves. For some crops, it may increase disease. Dahlias had powdery mildew under the Haygroves.
- Improved quality – Alex believes they would be great for producing a superior quality melon since they would control the amount of rain which often dilutes the sugars and causes splitting. They grew melons in the Haygroves the first year and they did great until the plastic had to be removed for an impending hurricane and then the melons all exploded!
- Provides season extension – doesn't just affect temperature but also wind and moisture. The multiple huge bays means there's a large area of air under there that cools off slower at night. The Haygroves were originally designed in England to keep strawberries dry, so they are designed more for controlling rainfall rather than temperature. However, the Hitts did have a surprise frost hot after planting their tomatoes – the ground outside was totally white and the tomatoes inside the tunnels were fine.

Disadvantages of Haygroves

- They are very difficult to construct if you have rocky soil, as the Hitts do. The legs are sunk 30 inches, and Alex had to use a jackhammer! This causes problems not only with initial installation but also makes it difficult to move them. To get around this problem, the Hitts are going to install another set of permanent legs, which the Haygroves can be moved to. This will allow them to have a three year rotation with the Haygroves.
- The Haygroves present a huge sail out in the field so you have to be prepared to vent them by pushing the plastic up very high. They are designed to withstand 70 mph winds. They were designed for England conditions where they don't get thunderstorms like we do that bring wind and rain at the same time. The Hitts have already had some bows bend due to a downdraft thunderstorm. They learned that come the first of May, they vent the tunnels, using ladders to push the plastic as high as they can. They make sure to roll the plastic up inside so it doesn't wrinkle and collect water running off the top – this would soon weigh it down and cause bending.
- They are not designed to take a snow load. They must be uncovered in winter. They can be used with sidewalls and end walls but they still are not designed for overwintering crops.

- Like any greenhouse, there will be a lot of water running off so you need to prepare for this when preparing the site. Make sure that when the water pours down the sides, it can run off between the rows and not across them. Alex digs a little trench in the leg row and seeds it with a cover crop to direct water out into the field.
- Would they do it again, knowing what they know now? Alex said they would. For them, it was a specific answer to a specific problem, and tomatoes were 16% of their business so it was worth solving that problem. For people who want to grow lettuce all season, a Haygrove is not for them. They should just get a high tunnel. The Haygroves are pretty labor-intensive, and it takes a couple of years to learn how to best manage them.

Shade

- Although season extension usually brings to mind an image of protecting plants from the cold, modifying temperatures in mid-summer can also be important. Shade over a bed can create a cool microclimate that will help prevent bolting and bitterness in heat-sensitive crops such as lettuce and spinach, make it possible to grow warm-weather crops in areas with very hot summers, and hasten germination of cool-weather fall crops.
- Some growers provide cooling shade by growing vines such as gourds on cattle panels or similar frames placed over the beds. Shade fabrics, available from greenhouse- and garden-supply companies, can be fastened over hoops in summer to lower soil temperatures and protect crops from wind damage, sunscald, and drying. Placing plants under 30 to 50% shade in midsummer can lower the leaf temperature by 10° F or more.
- Commercial shade fabrics are differentiated by how much sunlight they block. For vegetables like tomatoes and peppers, use 30% shade cloth in areas with very hot summers. For lettuce, spinach, and cole crops, use 47% in hot areas, 30% in northern or coastal climates. Use 63% for shade-loving plants. (The maximum shade density—80%—is often used over patios and decks to cool people as well as plants). Shade houses can also provide frost protection for perennials and herbs during winter. Temperatures inside can be as much as 20° F higher than outdoors.
  Source: ATTRA Season Extension Techniques for Market Gardeners

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Center for Crop Diversification Fact Sheet
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Soil Salinity in High Tunnel Production

Rachel Rudolph,[1] Ryan Lark[2] and Krista Jacobsen[3]

Understanding soil salinity in high tunnels

There is growing concern about increasing salinity in high tunnel soils, which is measured as soluble salt content. Soluble salts refer not only to sodium (Na^+), but also to other cations in the soil including potassium (K^+), calcium (Ca^+), and magnesium (Mg^+). Anions such as chloride (Cl^-) and nitrate (NO_3^-) are considered salts as well and are often applied in conjunction with K, Ca, or Na by way of fertilizers such as potassium nitrate (KNO_3), calcium nitrate ($CaNO_3$), or sodium nitrate ($NaNO_3$), among others. Soluble salts may also be introduced in soil amendments such as composts and manures, which may carry high levels of salts as well as phosphorus (P). When fertilizers and amendments are added to the soil in excess of the nutrients needed for crop production, they are not properly taken up by plants. This may lead to nutrients being leached through the soil profile or building up near the soil surface or in the crop root zone.

Because high tunnels are typically covered with plastic throughout the year, rain water is not able to affect the soil as it does in an open field environment. This lack of rain means there is far less water flow pushing nutrients deeper through the soil profile. Although this may limit nutrient leaching compared with the open field, this same process also means that salts are not being moved below the rooting zone to the extent they are in the field and may build up to levels that create nutrient imbalances and may even harm the crop (Figure 1).

Photo by Maya Horvath

Figure 1. Tomato plants were grown from March to August in a high tunnel with potassium nitrate applied weekly via fertigation. After removal of the plants and the woven weed mat barrier, salt on the soil surface can be observed (arrows).

Testing for soil salinity in high tunnels

There are several soil analyses available through various soil testing facilities (including the University of Kentucky's Regulatory Services Soil Testing Laboratory) that can help aid in understanding your high tunnel soil's salinity level. Although the tests described below are not part of a "routine soil test" package, they are recommended for high tunnel soils in order to know the content and concentration of the different salts in one's high tunnel soil, even before you suspect you may have a salinity issue. Requesting a soluble salts test on the soil test form is recommended. Many testing laboratories, including the University of Kentucky (UK) Regulatory Services Soil Testing Laboratory, measure soluble salts by measuring the electrical conductivity (EC) of a water extract from a mixture of 1 part soil and 2 parts water. This is referred to as $EC_{1:2}$. Since water is a poor conductor of electricity and dissolved salt ions are a good conductor of electricity, the EC of a soil is a representation of the amount of dissolved salts from the soil. It is important

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Table 1. General electrical conductivity ($EC_{1:2}$) readings and interpretation for vegetable production systems

$EC_{1:2}$ reading (mmhos/cm or dS/m)	Evaluation	Interpretation
0-0.40	Very low	Nutrient levels too low for normal growth
0.41-0.80	Low	Suitable for seedlings and salt sensitive plants
0.81-1.20	Normal	Standard range for most established vegetable crops; upper range for salt-sensitive crops
1.21-1.60	High	Possible reduced vigor and growth, particularly during high temperatures
1.61-3.20	Very high	Possible visible salt injury and reduced growth, including marginal leaf burn and wilting
>3.20	Extreme	Visible salt injury on most vegetable crops

to note that extraction methods for EC may vary, based on soil type and testing laboratory. Other methods of measuring soil EC involve different amounts of water added to soil which will affect the measurement and interpretation of results. Although EC is the standard method for measuring soil salinity for most testing labs in our region, other analyses are sometimes used, such as total soluble salts (TSS) which measures the total mass of dissolved ions in water and is in units of ppm. Total soluble salts is often used in conjunction with the concentration of sodium to evaluate sodium-related salinity (sodicity). Your soil test results should be accompanied by interpretations and recommendations from specialists. A general guide for interpreting $EC_{1:2}$ readings for vegetable production systems is listed in Table 1.

Cation exchange capacity (CEC) is also offered as part of the UK Regulatory Services Soil Testing. CEC is a representation of the cations held in the soil and the availability of nutrients. Clay soils have a higher CEC compared to sandy soils because of the naturally occurring negative charge of clay particles. A soil with a high CEC is generally considered beneficial because of the increased water and nutrient holding capacity of the soil. However, because a high CEC also means that the soil is less likely to leach cations, this may also contribute to increased soil salinity. Typical CEC values for soils of various textures are shown in Table 2. Common CEC values for Kentucky soils are 5 to 15 meq/100 g.

Percent base saturation (BS) is the portion of CEC occupied by the basic cations Ca^{2+}, Mg^{2+}, and K^{+}, as opposed to acidic cations, such as H^{+} and Al^{3+} (Sonon et al., 2017). This value is important in understanding soil fertility. Soils with a high percentage indicate a higher pH (more basic) and therefore have more of a buffer against acidic cations, which can be toxic to plant growth. Depending on the soil, percent BS can be a fraction of or almost equal to CEC.

Not all soil testing laboratories use the same method to determine CEC and base saturation. The UK Regulatory Services Lab provides a value for CEC and base saturation on all soil test reports estimated from routine test results of nutrients and pH. A direct analysis of soil CEC can be requested at an extra cost. For more information on the soil tests conducted and the methods used by UK Regulatory Services, visit https://www.rs.uky.edu/soil/.

Irrigation water may also naturally contain salts, such as Ca, Mg, and Na that may also contribute to increased soil salinity. It is important for growers to be aware of what elements are in the water used to irrigate their crops and how that water may affect the soil (and crops). Growers can submit a water sample for analysis at the University of Kentucky Regulatory Services Soil Testing Laboratory through the Kentucky Coop-

Table 2. Common CEC values for various soil textures.

Soil texture	CEC reading (meq/100g or cmol/kg)	Evaluation
Sand	1-5	Low CEC
Fine Sandy Loam	5-10	Medium CEC
Loam and Silt Loam	5-15	Medium-High CEC
Clay Loam	15-30	High CEC
Clay	>30	High CEC

Adapted from Cation Exchange Capacity and Base Saturation, University of Georgia Extension Circular 1040.

erative Extension Service or through private laboratories. For more information regarding water sample submission and interpretation of the analysis, please refer to UK-Ag Extension publication HO-111.

The effects of soil salinity on plants

Certain plants are more sensitive to soil salinity than others (Table 3). Sensitive plants will exhibit leaf tip burning and yellowing. The leaf margins may also look scorched. However, these symptoms may also be due to other nutrient imbalances or fertilizer burn. A leaf tissue analysis is recommended to confirm the problem. Crops that are sensitive to salts can suffer serious yield reductions. Plants may also display reduced growth that may result in shorter plants and smaller or fewer leaves (Figure 2).

Photo by Timothy Coolong

Figure 2. Tomato plants in the foreground were grown in soil with approximately 700 lb of Na per acre. Tomato plants in the background were growing in soil with 50-80 lb of Na per acre.

Preventing and remediating salinity in high tunnels

Prevention of the buildup of soluble salts is important to avoid crop yield losses and soil quality issues. Strong preventative measures may also greatly decrease the need to mitigate for high salt levels in the future. Growers can minimize the soluble salt inputs on the soil by limiting the amount of compost, manure, and nitrogen-based fertilizers applied to the soil. Growers should only apply what is needed for the crop and when the nutrients are in demand. This may mean reducing fertilizer inputs and splitting applications throughout the growing season. Consistent soil testing will be helpful in knowing how much, if any,

Table 3. Salt sensitivity of select vegetable crops

Vegetable crop	Soil salinity (EC_e) threshold without yield loss (mmhos/cm)	Salinity sensitivity rating
Bean	1	Sensitive
Beet	4	Moderately tolerant
Broccoli	2.8	Moderately tolerant
Cabbage	1.8	Moderately sensitive
Carrot	1	Sensitive
Cucumber	2.5	Moderately sensitive
Lettuce	1.3	Moderately sensitive
Onion	1.2	Sensitive
Pepper	1.5	Moderately sensitive
Sweet potato	1.5	Moderately sensitive
Potato	1.7	Moderately sensitive
Radish	1.2	Sensitive
Spinach	2	Moderately sensitive
Squash	3.2	Moderately tolerant
Strawberry	1	Sensitive
Tomato	2.5	Moderately sensitive
Zucchini	4.7	Moderately tolerant

Adapted from Soil Fertility and Fertilizers: An Introduction to Nutrient Management, 7th edition and Knott's Handbook for Vegetable Growers, 5th edition.

additional nutrients to amend to the soil. For recommendations on the amount of fertilizer to apply and when to apply split applications, please refer to UK ID-36 Vegetable Guide for Commercial Growers.

Cover cropping inside high tunnels is also a strategy that may prevent a buildup of soluble salts. Grass cover crops will help scavenge available nutrients in the soil, can help maintain or build soil organic matter levels, and may help growers reduce composts or other soil organic matter additions. Legume cover crops "fix" atmospheric nitrogen (N_2) via a symbiotic association with microbes in their roots and may provide a significant portion of the following crop's N demand. However, it should be noted that N fixation is significantly reduced if the soil nitrogen levels are already high, as in many high tunnels. In this case, a grass cover crop, such as cereal rye or millet, may be a better fit for the rotation. General recommended seeding rates and planting dates for many cover crops can be found in the Midwest Cover Crops Field Guide. For a copy of this field guide and for more regionally specific guidelines, contact your county extension agent.

Water management is the primary way to reduce soil salinity. Overhead irrigation of bare soil (when crops are not growing) may help leach salts far enough through the soil profile that they will not affect the future crop and can potentially be effective on soils with good structure and drainage. However, a considerable amount of water is required to leach any salts. Prior research indicated that approximately 6 inches of water is needed to leach salts through the soil profile (Table 4). However, a pilot study conducted at the University of Kentucky revealed that this may not be as effective as previously thought (Lark and Jacobsen, 2021). The pilot study was conducted on a Maury silt loam soil in Lexington, KY and evaluated high tunnel leaching using different water volumes applied by micro-jet sprinklers (Figure 3). The conclusion of the study was that 6 in of water did not leach a statistically significant amount of potassium or magnesium from the soil. However, applying 12 in of water leached approximately 60 lb of K/acre and 95 lb of Mg/acre, though this was much less than the formerly estimated 80%.

Table 4. Water volume required for leaching salts through soil profile

Water volume	Percent of salts leached below 12"
6"	50%
12"	80%
24"	90%

Courtesy of the California Fertilizer Association, Western Fertilizer Handbook, 8th Ed.

Photo by Ryan Lark

Figure 3. High tunnel soil prior to applying 6 and 12 inches of water using a 180° micro-jet sprayer. Photo was taken prior to applying any irrigation.

Another option for leaching salts may be to take advantage of the rainy season. When it is time to replace the plastic layers on a high tunnel (typically every four or five years), it may be useful to leave the high tunnel uncovered for several months (usually during the winter) to allow precipitation to naturally leach the salts through the soil and out of the root zone. Between the months of November and February, most regions in Kentucky have historically received approximately 15 inches of rain, which would be enough water volume to leach the majority of the salts past the root zone of vegetable crops.

Summary

Prevention of soil salinity through regular soil testing and well-informed applications of fertilizer to your soil will help set you up for future successful production in your high tunnel. The use of cover crops in the place of manure or compost will also help prevent soil salinity. However, buildup of salts in the soil is possible even with careful monitoring of the soil. That is why regularly allowing rain or heavy irrigation to push any salts past the root zone will also be an important aspect of soil salinity prevention.

If salt has already built up in the soil and prevention

is not possible, there are strategies for remediation. Leaving the high tunnel uncovered through the winter months to allow any salts to be leached past the root zone is an affordable and relatively easy method of remediation. Because it will take the high tunnel out of production, it may not be possible for all growers. Physically moving the high tunnel to another location on your farm may also be an option.

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Reviewed by Frank Sikora, UK Regulatory Services Director, Josh McGrath, UK Plant and Soil Sciences Associate Professor, and Hanna Poffenbarger, UK Plant and Soil Sciences Assistant Professor

Photos courtesy of Maya Horvath, UK Horticulture student (Pg. 1), Timothy Coolong, University of Georgia Horticulture Professor (Pg. 3), and Ryan Lark, UK Horticulture Research Analyst (Pg. 4) **March 2022**

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AGR-204

Cooperative Extension Service

Soils and Fertility

By Craig Cogger, Extension soil scientist, Washington State University. Adapted for Kentucky by Edwin Ritchey, Extension soils specialist, and Brad Lee, Extension water quality specialist, University of Kentucky.

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Soil is a mixture of weathered rock fragments (minerals) and organic matter at the earth's surface. It is biologically active—a home to countless microorganisms, invertebrates, and plant roots. It varies in depth from a few inches to eight feet or more. An ideal soil is roughly 50 percent pore space (50 percent voids between soil particles). This space forms a complex network of pores of varying sizes, much like those in a sponge. Soil provides nutrients, water, and physical support for plants as well as air for plant roots. Soil organisms are nature's primary recyclers, turning dead cells and tissue into nutrients, energy, carbon dioxide, and water to fuel new life.

Soil and Water

A productive soil is permeable to water and is able to supply water to plants. A soil's permeability and water-holding capacity depend on its network of two types of pores:

- Large pores (macropores) control a soil's permeability and aeration. Macropores include earthworm and root channels. Because they are large, water moves through them rapidly by gravity so that rainfall and irrigation infiltrate into the soil, and excess water drains through it.
- Micropores are fine soil pores, typically a fraction of a millimeter in diameter. They are responsible for a soil's water-holding capacity. Like the fine pores in a sponge or towel, micropores hold water against the force of gravity. Much of the water held in micropores is available to plants, but some is held so tightly that plant roots cannot use it.

Soil that has a balance of macropores and micropores provides adequate permeability and water-holding capacity for good plant growth. Soils that contain mostly macropores drain readily but are droughty and need more frequent irrigation. Soils that contain mostly micropores have good water-holding capacity but take longer to dry out, and excessive wetness can reduce plant growth.

Soil texture, structure, organic matter, and human activity affect porosity. You can evaluate your garden soil in terms of these properties to understand their impact. The only tools you need are your eyes, fingers, and a shovel.

Texture

Texture describes the relative abundance of sand, silt, and clay-sized materials. Anything greater than two millimeters in size is considered gravel or rock and is not soil. The coarsest soil particles are sand. They are visible to the eye and give soil a gritty feel. Silt particles are smaller than sand—about the size of individual particles of white flour. They give soil a smooth, floury feel. On close inspection, sand and silt particles look like miniature rocks (Figure 4.1).

Clay particles are the smallest—about the size of bacteria and viruses—and can be seen only with a microscope. They typically have a flat shape, similar to a sheet of mica, and when microscopically viewed from the side, they look like the pages of a book. Soils high in clay feel very hard when dry but are easily shaped and molded when moist.

Although all of these particles seem small, the relative difference in their sizes is quite large. If a typical clay particle were the size of a penny, a sand particle would be as large as a house.

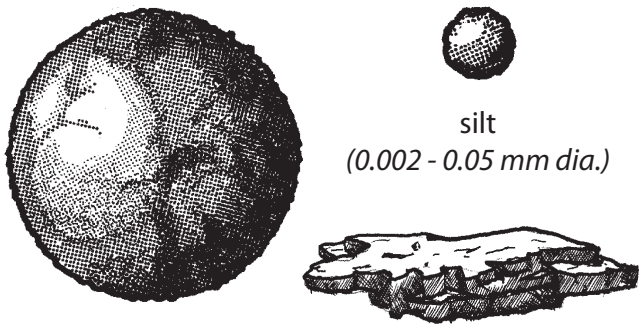

Figure 4.1. Shapes of soil particles.

Soil texture directly affects porosity. Pores between sand particles tend to be large, while those between silt and clay particles tend to be small. That means sandy soils contain mostly macropores and usually have rapid permeability but limited water-holding capacity. In soils containing mostly silt and clay, micropores predominate, creating high water-holding capacity but reducing permeability.

Particle size also affects the surface area in soil. Surface area is important because surfaces are the most active part of the soil. Soil surfaces hold plant nutrients, bind contaminants, and provide a home for microorganisms. Clay particles have a large surface area relative to their volume, so a small amount of clay makes a large contribution to a soil's surface area.

Nearly all soils have a mixture of particle sizes and pore sizes. As shown in Figure 4.2, a soil's textural class can be determined based on the percentages of silt, slay and sand that are present. A soil with roughly equal influence from sand, silt, and clay particles is called a loam. Loams usually make good agricultural and garden soils. They have a balance of macropores and micropores, so they usually have both good water-holding capacity and moderate permeability.

A sandy loam is similar to a loam, but it contains more sand. It feels gritty, yet has enough clay to hold together in your hand. Sandy loams usually have low to moderate water-holding capacity and good permeability.

Silt loams are richer in silt and feel smooth rather than gritty. They are pliable when moist but not very sticky. Silt loams usually have high water-holding capacity and low to moderate permeability. Much of Kentucky's surface soils have a silt loam texture.

Clays and clay loams are very hard when dry, sticky when wet, and can be molded into wires and ribbons when moist. They generally have low permeability and high water-holding capacity; however, much of this water is unavailable to plants.

For more information on soil textural determination, refer to the Cooperative Extension publication *Determining Soil Texture by Feel* (AGR-217). Almost any texture of soil can be suitable for gardening as long as you are aware of the soil's limitations and adjust your management to compensate. Clay soils hold a lot of water but are hard to dig and dry slowly in the spring. Sandy soils need more frequent watering and lighter, more frequent fertilization, but you can plant them earlier in the spring. All soils can benefit from additions of organic matter, as described later in this chapter under "Adding Organic Matter."

Many soils contain coarse fragments greater than two millimeters in diameter—gravel and rocks. Coarse fragments do not

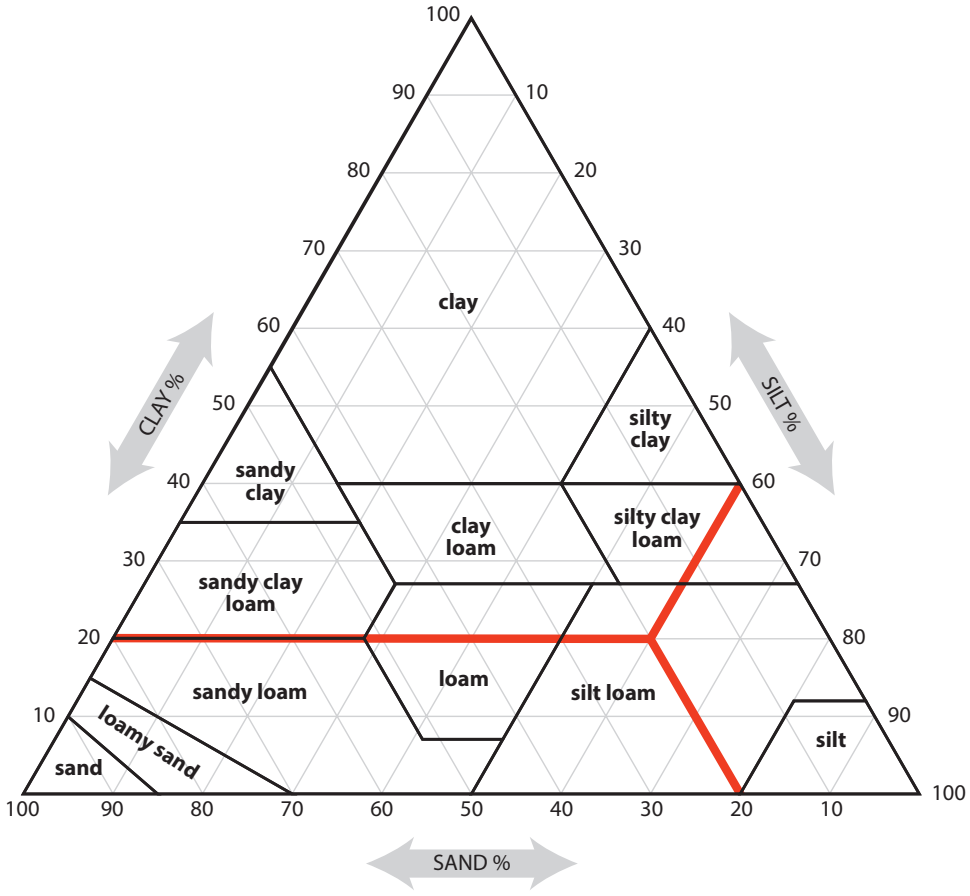

Figure 4.2. Basic soil textural classes can be determined based on percentages of clay, silt, and sand present. For example, a soil comprised of 20 percent sand, 60 percent silt and 20 percent clay, as highlighted in red, would be a silt loam.

contribute to a soil's productivity and can be a nuisance when you are digging. Don't feel compelled to remove all of them from your garden, however. Coarse fragments aren't harmful, and your time is better spent on other gardening tasks. The only time rocks are a problem is when you have nothing but rocks on your land. Then, water- and nutrient-holding capacities are so low that it is difficult to grow healthy plants.

Structure

Individual particles of sand, silt, and clay tend to cluster and bind together, forming aggregates called peds, which provide structure to a soil. Dig up a piece of grass sod and examine the soil around the roots. The granules of soil clinging to the roots are examples of peds. They contain sand, silt, clay, and organic matter.

Aggregation is a natural process caused largely by biological activity such as earthworm burrowing, root growth, and microbial action. Soil organic matter is an important binding agent that stabilizes and strengthens peds.

The spaces between peds are a soil's macropores, which improve permeability, drainage, and recharging of air into the soil profile. The pores within peds are predominantly micropores, contributing to the soil's water-holding capacity. A well-structured soil is like a sponge, allowing water to enter and soak into the micropores and letting excess water drain down through the macropores. Good structure is especially important in medium- to fine-textured soils (soils with appreciable amounts of clay), because it increases the soil's macroporosity, improving permeability and drainage.

Figure 4.3. Compacted soil resists root penetration and water movement.

Human Activity

Soil structure is fragile and can be damaged or destroyed by compaction, excessive tillage, or tilling when the soil is too wet. Loss of organic matter, typically a result of tillage, also weakens structure.

Compaction squeezes macropores into micropores and creates horizontal aggregates that resist root penetration and water movement (Figure 4.3). Compaction often occurs during site preparation or house construction, creating a difficult environment for establishing plants. Protect your soil from compaction by avoiding unnecessary foot or machine traffic.

Tilling when soil is too wet also damages soil structure. If you can mold a piece of soil into a wire or worm in your hand, it is too wet to till, and traffic should be avoided until it dries. If the soil crumbles when you try to mold it, it is dry enough to till.

Structural damage caused by human activity usually is most severe within the top foot of soil and can be overcome by proper soil management.

Organic Materials, Organic Matter, and Humus

Organic materials (called organic residues), such as plant and animal residues of recognizable origin, are the building blocks of organic matter, or humus. Soil organic matter and humus (terms often used synonymously) contain decomposed plant and animal remains of unrecognizable origin, their partial decomposition products, and the wastes from soil biomass.

Increasing soil organic matter is the best way to improve the plant environment in nearly all soils, because it helps build and stabilize soil structure in fine-textured and compacted soils, improving permeability and aeration and reducing the risk of runoff and erosion. Organic matter is less susceptible to compaction than the mineral components of soil and can reduce compaction potential. In addition, when organic material decomposes, it forms humus, which acts as a natural glue to bind and strengthen soil aggregates. Organic matter also helps soils, particularly sandy soils, hold water and nutrients and is a reservoir of energy for soil microbes. See "Adding Organic Matter" later in this chapter for more information.

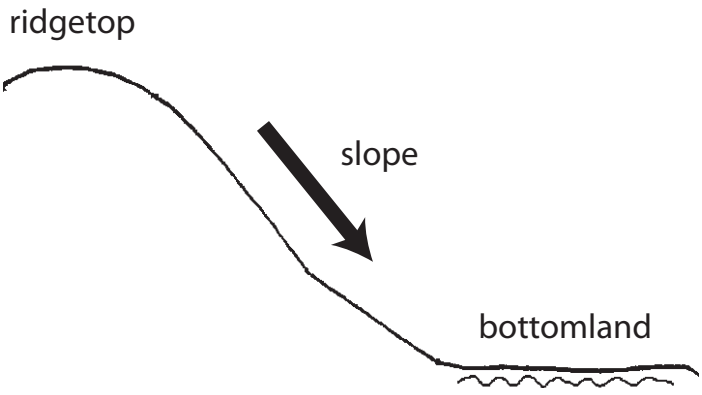

Figure 4.4. Ridgetops and slopes tend to shed water, while soils at the bottom of slopes and in low areas collect water.

Water Management in Your Garden

Slope, Aspect, and Soil Depth

Slope, aspect (direction of exposure), and soil depth affect availability of water and its use in a soil. Choose plants that are best suited to your property's conditions.

Ridgetops and side slopes tend to shed water, while soils at the bottom of slopes and in low areas collect it (Figure 4.4). Soils that collect water often have high winter water tables, which can affect the health of some plants. Soils on ridgetops are more likely to be droughty.

Site aspect also is important. Exposures facing south or southwest collect the most heat and use the most water.

Soil depth also affects water availability by determining the rooting zone. Soil depth is limited by compacted, cemented, or gravelly layers, or by bedrock. A shallow soil has less available water simply because the volume of soil available to roots is smaller. Dig below the topsoil in your garden. The deeper you can dig before hitting a restrictive layer, the greater the soil volume for holding plant-available water.

See the Cooperative Extension publication *Improving the Productivity of Landscapes with Little or No Topsoil* (AGR-203) for more information.

Irrigation

Most gardens in Kentucky require summer irrigation. The need for irrigation varies, depending on soil water-holding capacity, weather, site aspect, the plants grown, and the plants' growth stage.

In most cases, the goal of irrigation is to recharge the available water in the top foot or so of soil. For sandy soil, one inch of irrigation water is all you need. Any more will leach (move downward) through the root zone, carrying nutrients with it. A silt loam or clay soil can hold more than two inches of water, but you may need to irrigate more slowly to prevent runoff.

Wet Soils

If your soil stays wet in the spring, you will have to delay tilling and planting. Working wet soil can damage its structure, and seeds are less likely to germinate in cold, wet soil.

Some plants don't grow well in wet soil. Raspberries, for example, often become infected by root diseases in wet soil and lose vigor and productivity.

A soil's color gives clues to its tendency to stay wet. If a subsoil is brown or reddish, the soil probably is well drained and is rarely too wet. Gray subsoils, especially those with brightly colored mottles, often are wet. If your soil is gray and mottled directly beneath the topsoil, it will be saturated in some part of the year.

Sometimes, simple practices can reduce problems with wet soil, including the following:

- Divert runoff from roof drains away from your garden.
- Avoid plants that perform poorly in wet conditions.
- Use raised beds for perennials that require well-drained soil and for early-season vegetables.
- Investigate whether a drain on a slope will remove excess water on your property. Installing drainage can be expensive, however. When considering drainage, make sure there is a place to drain the water. Check with local regulatory agencies about any restrictions on the project.

Organisms

Soil abounds with life. Besides the plant roots, earthworms, insects, and other creatures you can see, soil is home to an abundant and diverse population of microorganisms.

Soils with more organic matter tend to have more microorganisms—and the more microorganisms, the better. The important thing is to make the environment favorable for microorganism activity, which includes well-aerated soils that are warm and moist, with near-neutral pH and good levels of organic matter. Other factors must also be considered; for example, if trying to grow blueberries, which like more acidic conditions, this constraint for plant growth would be more important than a near-neutral pH for microbial growth. You must first satisfy the needs of the plant.

Table 4.1. Approximate abundance of microorganisms in agricultural topsoil.

Organism	Number/Gram (Dry-Weight Basis)
Bacteria	100 million to 1 billion
Actinomycetes	10 million to 100 million
Fungi	100,000 to 1 million
Algae	10,000 to 100,000
Protozoa	10,000 to 100,000
Nematodes	10 to 100

A single gram of topsoil (about one-quarter teaspoon) can contain as many as a billion microorganisms (Table 4.1). Microorganisms are most abundant in the rhizosphere—the thin layer of soil surrounding plant roots.

The main function of soil organisms is to break down the remains of plants and other organisms. This process releases energy, nutrients, and carbon dioxide and creates soil organic matter.

Organisms ranging from tiny bacteria to insects and earthworms take part in a complex soil food web (Figure 4.5). Mammals such as moles and voles also are part of the food web, feeding on insects and earthworms and mixing organic matter throughout the soil profile. This mixing also improves soil structure.

Some soil organisms play other beneficial roles. Mycorrhizae are fungi that infect plant roots and increase their ability to take up nutrients from the soil. Rhizobia bacteria are responsible

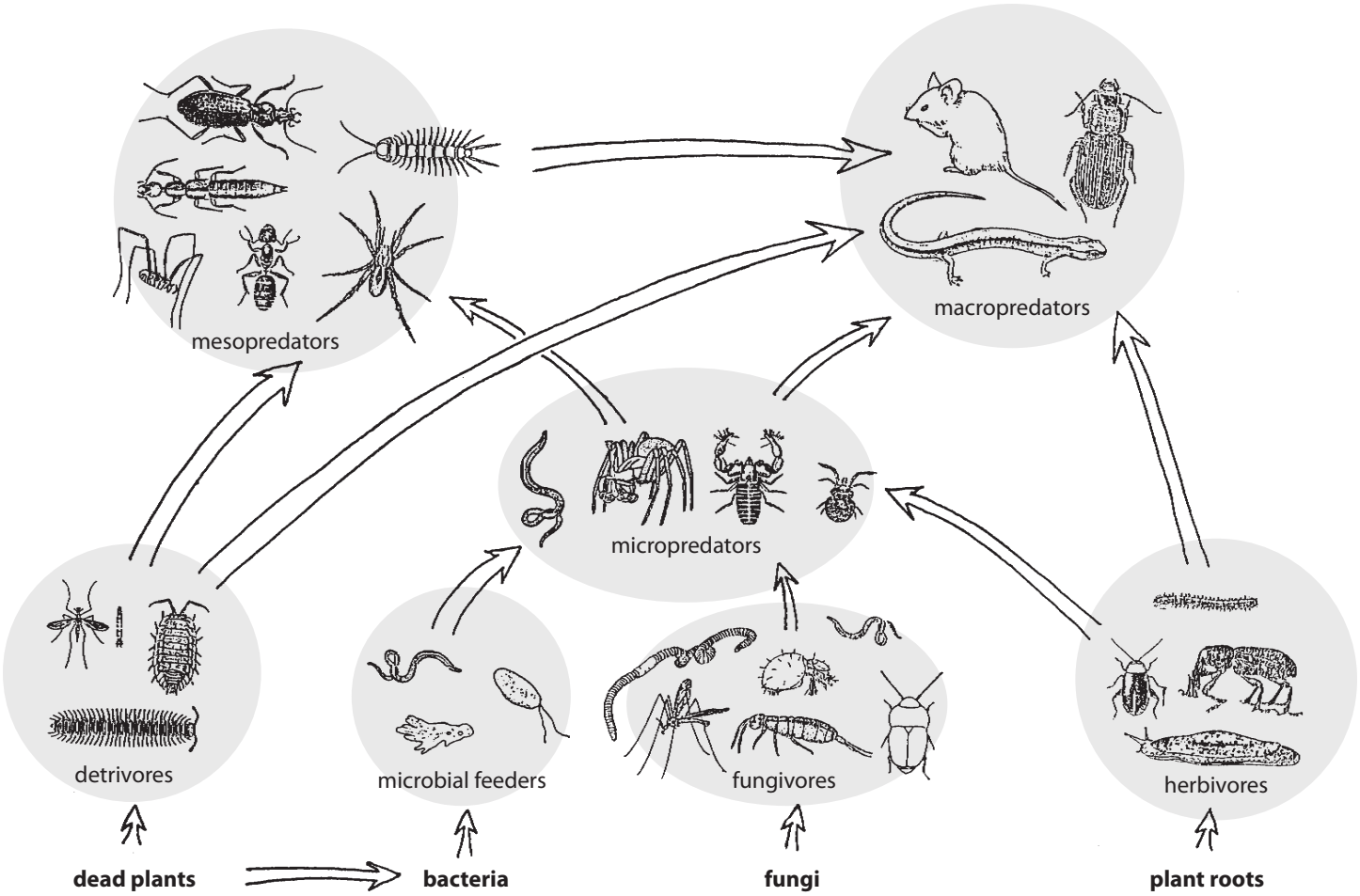

Figure 4.5. The soil food web.

for converting atmospheric nitrogen to plant-available forms, a process known as nitrogen fixation. Earthworms mix large volumes of soil and create macropore channels that improve permeability and aeration (Figure 4.6). "Soil health" is often judged by the numbers of earthworms in the soil—the more earthworms, the better.

Not all soil organisms are beneficial. Some are pathogens, which cause diseases such as root rot of raspberries and scab on potatoes. Moles can damage crops and lawns, and slugs are a serious pest in many Kentucky gardens.

The activity of soil organisms depends on soil moisture and temperature as well as on the soil's organic matter content. Microorganisms are most active between 70°F and 100°F, while earthworms are most active and abundant at soil temperatures of about 50°F. Most organisms prefer moist soil. The relationships between gardening practices, microbial populations, and soil quality are complex and often poorly understood. Almost all gardening activities—including tillage; the use of fertilizers, manures, and pesticides; and the choice of crop rotations—affect the population and diversity of soil organisms. For example, amending soils with organic matter, returning crop residues to the soil, and rotating plantings tend to increase the number and diversity of beneficial organisms.

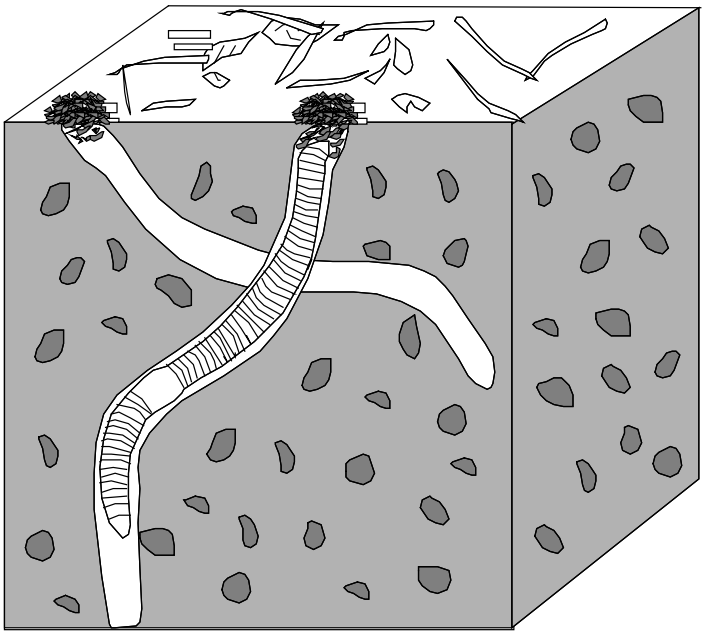

Figure 4.6. Earthworm channels create macropores, which improve a soil's permeability and aeration.

Table 4.2. Essential plant nutrients.

Primary Nutrients (Macronutrients)		Secondary Nutrients		Micronutrients (Trace Nutrients)	
Name	**Chemical Symbol**	**Name**	**Chemical Symbol**	**Name**	**Chemical Symbol**
Nitrogen	N	Sulfur	S	Zinc	Zn
Phosphorus	P	Calcium	Ca	Iron	Fe
Potassium	K	Magnesium	Mg	Copper	Cu
				Manganese	Mn
				Boron	B
				Molybdenum	Mo
				Chlorine	Cl

Nutrients

Soil supplies 13 essential plant nutrients. Each nutrient plays one or more specific roles in plants. Nitrogen (N), for example, is a component of chlorophyll, amino acids, proteins, DNA, and many plant hormones. It plays a vital role in nearly all aspects of plant growth and development, and plants need a lot of nitrogen to grow well. In contrast, plants need only a tiny amount of molybdenum, which is involved in the functioning of only a few plant enzymes. Molybdenum nonetheless is essential, and plant growth is disrupted if it is deficient. Plants also require carbon, hydrogen, and oxygen, which they derive from water and air.

A soil nutrient is classified as a primary nutrient (macronutrient), secondary nutrient, or micronutrient, based on the amount of the nutrient needed by plants (Table 4.2). If a soil's nutrient supply is deficient, fertilizers can provide the additional nutrients needed for healthy plant growth.

Deficiencies

The most common nutrient deficiencies are for the primary nutrients—nitrogen, phosphorus (P), and potassium (K)—which are in largest demand by plants. Nearly all soils lack enough available nitrogen for ideal plant growth. Unlike many states in the United States, Kentucky's urban soils typically have an abundance of phosphorus and potassium.

Secondary nutrients also are deficient in some Kentucky soils, but not very often. The secondary nutrients are calcium (Ca), magnesium (Mg), and sulfur (S). Calcium and magnesium are almost always sufficient when proper pH management practices are followed. Micronutrient deficiencies do occur in Kentucky, but to a limited extent. Maintaining proper soil pH typically alleviates most micronutrient deficiency issues.

Except for boron and zinc, micronutrients are rarely deficient. Boron deficiencies occur most often in root crops, brassica crops (e.g., broccoli), and caneberries (e.g., raspberries). Zinc deficiency usually is associated with high phosphorus levels and high pH soils and most often affects tree fruits and corn.

Each nutrient deficiency causes characteristic symptoms. In addition, deficient plants grow more slowly, yield less, and are less healthy than plants with adequate nutrient levels.

Because most soil in the central and outer Bluegrass region of Kentucky has been formed from limestone that is naturally high in phosphorus, plant-available phosphorus is very high (exceeding 200 pounds per acre), and soils in the Bluegrass region may never need phosphorus fertilization. Adding fertilizer phosphorus in this region simply increases the chances for eutrophication (algal blooms that may cause fish kills) and can diminish the uptake of other essential plant nutrients like zinc. Since fertilizer analysis is given in percent of N, $P_2 0_5$, and $K_2 0$, make certain that the center number in a fertilizer product is zero (for example 23–0–30) when soils have adequate or high amounts of phosphorus.

Outside of the Bluegrass area, research has identified elevated levels of phosphorus in all urban areas of the state, regardless of physiographic region. Likely this is due to continuous overapplication of phosphorus fertilizers in lawns and gardens across the Commonwealth. Therefore it is imperative that all phosphorus fertilizer application rates be based upon a soil test result and a recommendation from your local county Cooperative Extension Service agent.

Long-term use of complete fertilizers or animal manures can also increase phosphorus concentrations to levels so that no additional phosphorus is required, which is another reason to soil test before applying nutrients—so you will know what nutrients are needed and the correct amount to add.

Excess Nutrients

Excess nutrients can be a problem for plants and the environment. Excesses usually occur because too much of a nutrient is applied or it is applied at the wrong time.

Too much boron is toxic to plants. Too much nitrogen can lead to excessive foliage production, increasing the risk of disease; wind damage; and delayed flowering, fruiting, and dormancy. Available nitrogen left in the soil at the end of the growing season can leach into groundwater and threaten drinking water quality.

The key to applying fertilizers is to meet plant needs when the plant needs it without creating excesses that can harm plants or the environment.

Nutrient Availability to Plants

Plants can take up only nutrients that are in solution (dissolved in soil water). Most soil nutrients are not in solution but instead are tied up in soil mineral and organic matter in

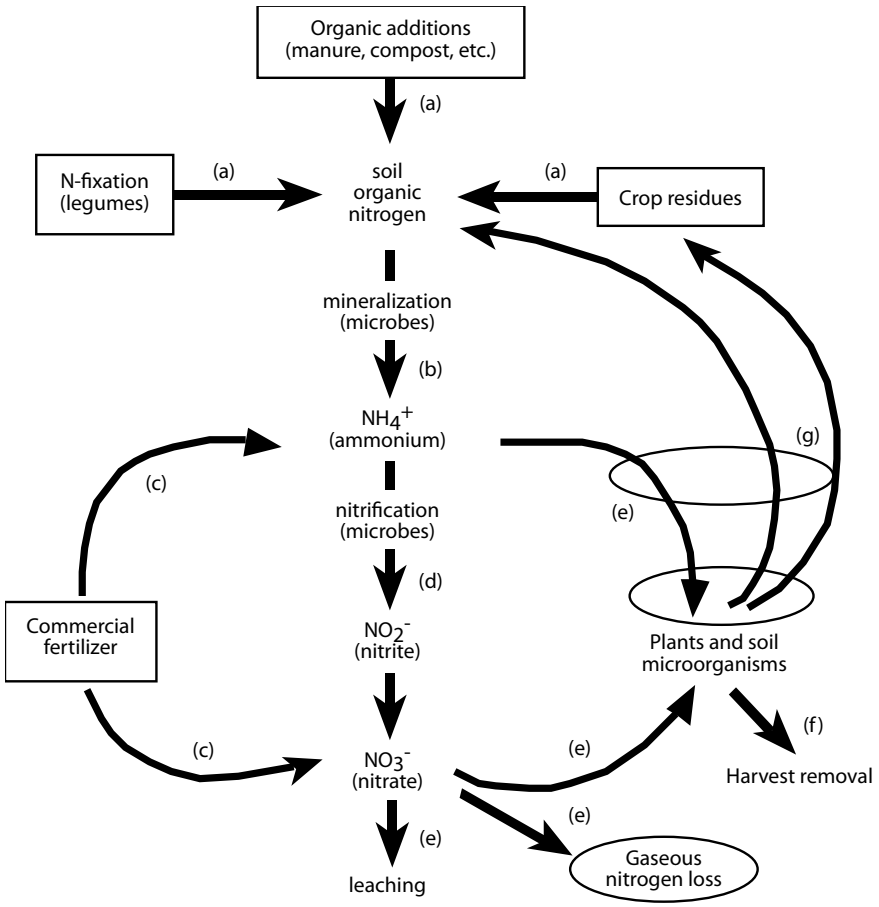

Figure 4.7. Nitrogen cycle:
a. Legumes, soil organic matter, crop residues, and organic additions (manures, composts, etc.) are sources of organic N.
b. Organic N is mineralized into ammonium (NH_4^+) by soil microbes.
c. Commercial fertilizer supplies N as ammonium or nitrate (NO_3^-).
d. Microbes nitrify ammonium to nitrite and then nitrate.
e. Plants, microorganisms, leaching below the root zone, and release of gaseous N to the atmosphere remove N from the root zone soil solution.
f. Crop harvest removes N stored in plants.
g. Nitrogen present in both crop residues and soil microorganisms becomes a part of the soil organic N content.

(Note: An alternate schematic of the nitrogen cycle is illustrated in Chapter 12, Your Yard and Water Quality.)

insoluble forms. These nutrients become available to plants only after they are converted to soluble forms and dissolve in the soil solution.

This process occurs through weathering of mineral matter and biological decomposition of organic matter. Weathering of mineral matter is a very slow process that releases small amounts of nutrients each year. The rate of nutrient release from soil organic matter is somewhat faster and depends on the amount of biological activity in the soil.

Nutrient release from soil organic matter is fastest in warm, moist soil and nearly nonexistent in cold or dry soil. Thus, the seasonal pattern of nutrient release is similar to the pattern of nutrient uptake by plants. About one to four percent of the nutrients in soil organic matter are released in soluble form each year.

Soluble, available nutrients are in ionic form, meaning they have either positive or negative charges. Positively charged ions are cations, of which potassium, calcium, and magnesium are examples. Negatively charged ions are anions. Chlorine and nitrates are examples of anions.

Clay particles and soil organic matter have negative charges on their surfaces and can attract cations. They hold nutrient cations in ready reserve for rapid release into soil solution to replace nutrients taken up by plant roots. This reserve supply of nutrients contributes to a soil's fertility. A soil's capacity to hold cations is called its cation exchange capacity, or CEC.

The Nitrogen Cycle

Managing nitrogen is a key part of growing a productive and environmentally friendly garden. Nitrogen is the nutrient needed in the largest amount by plants, but excess nitrogen can harm plants and degrade water quality. Understanding how the nitrogen cycle affects nitrogen availability can help you become a better nutrient manager (Figure 4.7).

Table 4.3. Common forms of nitrogen in soil.

Form of Nitrogen	Characteristics
Organic N	Primary form of N in soil. Found in proteins, lignin, amino acids, humus, etc. Not available to plants. Mineralized to ammonium by soil microorganisms.
Ammonium N (NH_4^+)	Inorganic, soluble form. Available to plants. Converted to nitrate by soil microorganisms.
Nitrate (NO_3^-)	Inorganic, soluble form. Available to plants. Can be lost by leaching. Converted to gases in wet soils.
Atmospheric N (N_2)	Makes up about 80% of the soil atmosphere. Source of N for N-fixing plants. Not available to other plants.

Note: Any nitrogen source that contains ammonium or has an ammonium intermediary is acid forming.

Nitrogen is found in four different forms in the soil (Table 4.3). Only two of them, ammonium and nitrate, can be used directly by plants.

Most nitrogen in soil is tied up in organic matter and plant, animal, and microbial biomass. This organic nitrogen is not available to plants. As soil warms in the spring, soil microbes begin breaking down organic matter, releasing some of the nitrogen as ammonium (NH_4^+). Any nitrogen source that contains ammonium or has an ammonium intermediary is acid forming. Urea, $(NH_2)_2CO$, will form NH_4^+ when applied to the soil. When the soil is warm, a group of microbes called nitrifiers convert the ammonium to nitrate (NO_3^-). When the nitrifiers convert the NH_4^+ to NO_3^-, they release H^+ (acidity), which will lower soil pH. On the other hand, nitrate forms (NO_3^-) are not acid forming. Ammonium, retained by the soil due to its positive charge, is a soluble ion that is available to plants and soil microbes. Nitrate is also soluble and available to plants. The ammonium and nitrate ions released from soil organic matter are the same as the ammonium and nitrate contained in processed fertilizers.

Because nitrate has a negative charge, it is not held to the surface of clay or organic matter, so it can be lost readily by leaching. Nitrate remaining in the soil at the end of the growing season will leach during the fall and winter and may reach groundwater, where it becomes a contaminant. In soils that are saturated during the wet season, soil microbes convert nitrate to nitrogen gases, which diffuse back into the atmosphere.

Ammonium and nitrate taken up by plants are converted back to organic forms in plant tissue. When plant residues are returned to the soil, they decompose, slowly releasing nitrogen back into the soil as plant-available forms.

The nitrogen cycle is a leaky one, with losses to leaching and the atmosphere. Harvesting crops also removes nitrogen. To maintain an adequate nitrogen supply, nitrogen must be added back into the system through fixation or fertilization.

Nitrogen fixation is a natural process involving certain plants and Rhizobia bacteria. The Rhizobia form nodules in the plant roots, and through these nodules they are able to take atmospheric nitrogen (N_2 gas) from the soil air and convert it to available nitrogen within the plant. Legumes (plants that produce seeds in pods) such as peas, beans, alfalfa, and clover are common nitrogen fixers. The Kentucky coffeetree, the honey locust, redbuds, and Alder trees also fix nitrogen. Growing legumes as a cover crop will supply nitrogen to future crops.

Understanding Fertilizers

Fertilizers supplement a soil's native nutrient supply. They are essential to good plant growth when the soil nutrient supply is inadequate. Rapidly growing plants such as annual vegetable crops generally need more nutrients than slowly growing plants such as established perennials.

You can use processed fertilizers, organic fertilizers, or a combination of the two to supply soil nutrients. Plants do not prefer one source of nutrients over another, but the nutrients' behavior in the soil often differs (Table 4.4).

Processed fertilizers are manufactured or refined from natural ingredients to make them more concentrated and more available to plants. Typically, they are processed into soluble, ionic forms that are immediately available to plants.

Organic fertilizers are natural materials that have undergone little or no processing. They include both biological (plant and animal) materials and mineral materials.

Once in the soil, organic fertilizers release nutrients through natural processes, including chemical weathering of mineral materials and biological breakdown of organic matter. The released nutrients are available to plants in water-soluble forms. These soluble forms of nutrients are the same as those supplied by processed fertilizers.

When compared with processed fertilizers, organic fertilizers usually have a lower concentration of nutrients and release

Table 4.4. Comparing organic and processed fertilizers.

	Organic Fertilizers	Processed Fertilizers
Source	Natural materials; little or no processing	Manufactured or extracted from natural materials; often undergo extensive processing
Examples	Manure, cottonseed meal, rock phosphate, fish by-products	Ammonium sulfate, processed urea, diammonium phosphate (DAP), potassium chloride
Nutrient Availability	Usually slow-release; nutrients are released by biological and chemical processes in soil	Nutrients usually are almost immediately available to plants
Nutrient Content	Usually low	Usually high

nutrients more slowly. That means larger amounts of organic fertilizers are needed, but their effects last longer.

Using organic fertilizers recycles materials that otherwise would be discarded as wastes. Production of processed fertilizers, on the other hand, can create wastes and use substantial amounts of energy.

Choosing organic fertilizers involves trade-offs in cost or convenience. Farmyard manure usually is inexpensive or free, but can be inconvenient to apply. Packaged organic blends, on the other hand, are convenient but often more expensive.

Nutrient Release

Nutrients in most processed fertilizers are available almost immediately. Processed fertilizers can furnish nutrients to plants in the spring before the soil is warm. However, nitrogen in these fertilizers is vulnerable to leaching loss from heavy rainfall or irrigation. Once nitrogen moves below the root zone, plants no longer can use it, and it may leach into groundwater.

Organic fertilizers are slow-release fertilizers because their nutrients become available to plants over the course of the growing season. The rate of nutrient release from organic materials depends on the activity of soil microorganisms, just as it does for nutrient release from soil organic matter. Temperature and moisture conditions that favor plant growth also favor the release of nutrients from organic matter.

Some organic fertilizers contain immediately available nutrients as well as slow-release nutrients. These fertilizers can supply nutrients to plants both early in the season and later. Fresh manure, biosolids, and fish emulsion are examples of organic fertilizers containing available nutrients.

We assume that in manures, 100 percent of potassium (potash) is available the first year, along with 80 percent of phosphorus and about 50 percent of the nitrogen. Remember that nitrogen values vary depending on the type of manure, the environmental conditions during the growing season, and when during the season the manure was applied.

As manure ages, the most readily available nutrients are lost into the air or leached into the soil, leaving slow-release material in the aged manure.

Some material in organic fertilizers breaks down so slowly that it is not available the first season after application. Repeated application of organic fertilizers builds up a pool of material that releases nutrients very slowly. In the long run, this nutrient supply decreases the need for supplemental fertilizer.

Fertilizer Labels

The labels on fertilizer packages tell the amount of each of the three primary nutrients in the fertilizer, expressed as a percent of total fertilizer weight. Nitrogen (N) always is listed first, phosphorus (P) second, and potassium (K) third.

Historically, the amount of phosphorus in fertilizer has been expressed not as P, but as units of the oxide form P_2O_5 (phosphate). Similarly, fertilizer potassium is expressed as K_2O (potash). This practice still is used for fertilizer labels and recommendations, even though there is no practical reason for the system except that people are accustomed to it. (If you need to convert from P to P_2O_5, the conversion is:

$$1 \text{ lb } P = 2.29 \text{ lb } P_2O_5$$

For potassium, the conversion is:

$$1 \text{ lb } K = 1.2 \text{ lb } K_2O$$

Thus, a bag of fertilizer labeled 5–10–10 contains 5 percent nitrogen, 10 percent phosphate (4.4 percent phosphorus), and 10 percent potash (8.3 percent potassium). This information is called a fertilizer analysis.

The analysis for processed fertilizers guarantees the amount of available nutrients in the fertilizer. The analysis for organic fertilizers represents the total amount of nutrients rather than available nutrients. Because nutrients in most organic fertilizers are released slowly, the amount of immediately available nutrients is less than the total.

Common Processed Fertilizers

Nitrogen

The raw material for processed nitrogen fertilizer is nitrogen gas from the atmosphere. The manufacturing process is the chemical equivalent of biological nitrogen fixation and requires a substantial amount of fossil fuel energy. Examples of processed nitrogen fertilizers available for home garden use include those listed in Table 4.5.

Table 4.5. Examples of processed nitrogen fertilizer materials.

Material	Analysis	Comments
Urea	46-0-0	Rapidly converted to ammonium in soil.
Ammonium sulfate	21-0-0	Also contains 24% available sulfur. Used with acid-loving plants.
Diammonium phosphate	18-46-0	Used in mixed fertilizers as a source of nitrogen and phosphorus.
Sulfur-coated urea (SCU)	35-0-0	Sulfur coating slows release of available N, making this a slow-release fertilizer.

Phosphorus and Potassium

Processed phosphorus fertilizers come from phosphate rock. The rock is treated with acid to release phosphorus into plant-available forms.

The most common raw material for potassium fertilizers is sylvinite, a mixture of sodium chloride and potassium chloride salts. The potassium in sylvinite is already in soluble form, but the sylvinite is treated to remove the sodium salts to make it suitable for use as a fertilizer. Some other potassium fertilizers are made from potassium sulfate salts, which supply sulfur as well as potassium. Table 4.6 lists examples of processed phosphorus and potassium fertilizers.

Table 4.6. Examples of processed phosphorus and potassium fertilizer materials.

Material	Analysis	Comments
Monoammonium phosphate	11–52–0	Used in mixed fertilizers as a source of nitrogen and phosphorus.
Diammonium phosphate	18–46–0	Used in mixed fertilizers as a source of nitrogen and phosphorus.
Potassium chloride	0–0–60	High salt index.
Potassium magnesium sulfate	0–0–22	Also contains 11% magnesium and 18% sulfur.
Potassium sulfate	0–0–50	Also contains 18% sulfur.

Table 4.7. Typical nitrogen, phosphate, and potash content (%) of some manures.

Animal Manures[1]	Water (%)	Nutrients (%)		
		N*	P_2O_5	K_2O
Dairy Cattle	80	0.55	0.45	0.60
Beef	80	0.55	0.35	0.50
Poultry Litter	20	2.75	2.75	2.25
Goat	70	1.10	0.25	0.75
Horse	80	0.60	0.30	0.60

1 Animal manures contain chloride, which can reduce the quality of some crops.
* Plant-available N can range from 20% to 80% of the total N in the year of application. See UK Cooperative Extension publication *Using Animal Manures as Nutrient Sources* (AGR-146) for more details.
This table was taken from UK Cooperative Extension publication *Lime and Fertilizer Recommendations* (AGR-1).

Mixed Fertilizers

Mixed, or complete, fertilizers contain all three primary nutrients. The ratios can vary. Fertilizers for annual gardens typically have $N:P_2O_5:K_2O$ ratios in the range of 1:1:1 or 1:2:2. Examples include 8–8–8 and 10–20–20 blends. Fertilizer blends for starting plants usually have a higher proportion of phosphorus. Lawn fertilizers are higher in nitrogen; an example is a 12–4–8 blend.

Common Organic Fertilizers

Farmyard manure can be an inexpensive source of nutrients. If you or your neighbors have livestock, it makes environmental and economic sense to recycle the manure as fertilizer. Packaged manure products cost more than manure off the farm, but they usually are more uniform and convenient to handle.

Animal manures vary widely in nutrient content and nutrient availability, depending on the type of animal that produced the manure and the manure's age and handling. For example:

- Fresh manure has higher nutrient levels than aged manure.
- Manure diluted with large amounts of bedding has fewer nutrients than undiluted manure.
- Exposure to rain leaches nutrients.
- Composting under cover retains more nutrients but reduces nutrient availability.

Table 4.7 compares average nutrient contents of typical manure products.

It doesn't take much fresh manure to fertilize a garden. One five-gallon bucket of fresh cow manure is enough for about 50 square feet of garden. The same amount of fresh poultry manure covers 100-150 square feet. Larger amounts can harm crops and leach nitrogen into groundwater. Sampling manure and testing for nutrient content is the best approach to matching plant needs with nutrient content of the manure.

Fresh manure can carry disease-causing pathogens. Be sure to refer to the information on manure safety below before using fresh manure.

It takes larger amounts of aged, diluted, or leached manure to provide the same amount of nutrients as fresh manure. If you're using it, increase the amount applied based on how much it is aged, diluted, and/or leached. Composted manure solids from dairy farms also have low nutrient availability, so you can apply them at higher rates than fresh manure. Use these manures as much for the organic matter they supply as for nutrients. You can add as much as one to two inches of manure and still have very low nutrient availability.

To fine-tune your application rate, experiment with the amount you apply and observe your crops' performance. It's better to be conservative and add more nutrients later if crops seem deficient than to risk overfertilizing.

To use manure, simply spread it over the soil and turn it in if you wish. Turning the manure in will help conserve some of the nitrogen in the manure and reduce the potential to lose manure due to runoff. However, tillage does increase erosion potential.

The best time to apply manure is in the spring before planting. You also can apply manure in the fall, but environmental risks of leaching and runoff increase in winter. If you do apply manure in the fall, apply it early and plant a cover crop to help capture nutrients and prevent runoff. See "Green Manure (Cover Crops)" later in this chapter for more information.

Using Manure Safely

Fresh manure sometimes contains disease-causing pathogens that can contaminate garden produce. *Salmonella* bacteria are among the most serious pathogens found in animal manure. Pathogenic strains of *E. coli* bacteria also can be present in cattle manure. Manure from swine, dogs, cats, and other carnivores should not be used in home gardens as it can contain helminths, which are parasitic worms.

These pathogens are not taken up into plant tissue, but they can adhere to soil on plant roots or to the leaves or fruit of low-growing crops. The risk is greatest for root crops (for example, carrots and radishes) or leaf crops (such as lettuce), where the edible part touches the soil. The risk is negligible for crops such as sweet corn, which do not contact the soil, or for any crop that is thoroughly cooked. Avoid using fresh manure where you grow high-risk crops.

Cooking destroys pathogens, but raw food carries a risk. Washing and peeling raw produce removes most pathogens, but some may remain.

Composting manure at high temperatures kills pathogens, but it is very hard to maintain rigorous composting conditions in a backyard pile. Commercial manure composts are composted under controlled conditions to destroy pathogens.

Bacterial pathogens die naturally over a period of weeks or months, so well-aged manure should not contain them. Helminths in dog, cat, or pig manure can persist for years, so do not add these manures to your garden or compost pile.

Biosolids

Biosolids are a by-product of wastewater treatment. Most of the biosolids produced in Kentucky are used to fertilize agricultural and forest crops. Biosolids also are available to gardeners from some wastewater treatment plants.

Use only biosolids that are free of disease-causing pathogens (Class A biosolids). Examples include biosolids compost and some heat-treated biosolids. Class B biosolids have not been treated to the same extent and may contain pathogens, including some that are long-lived in the soil. Check with the wastewater treatment plant offering biosolids to find out whether its biosolids meet Class A requirements and are available for home use.

A common form of biosolids is a spongy, black substance called "cake." Biosolids cake is about 20 percent to 25 percent dry matter and 75 percent to 80 percent water. It typically contains about 3 percent to 6 percent nitrogen and 2 percent to 3 percent phosphorus on a dry-weight basis, as well as small amounts of potassium and trace elements. Some of the nitrogen in biosolids is immediately available to plants. The rest is released slowly. Nutrient application of biosolids should be based on the nutrient content of the material being used. A nutrient analysis should be available from where the biosolid was processed.

Biosolids also are an ingredient in some commercial composts. Like other composts, biosolid compost releases nutrients very slowly (other than the immediately released nitrogen). It is a good source of organic matter and provides small amounts of nutrients to plants.

Biosolids contain small amounts of trace elements. Some trace elements are micronutrients, which can be beneficial to crops. However, large amounts can be toxic to crops, animals, or humans. When you apply biosolids at proper rates to provide nutrients, the risk of applying harmful amounts of trace elements is negligible.

Because biosolids come from the wastewater treatment process, they contain synthetic materials that were present in the wastewater or added during treatment. Biosolids are not certified as organic fertilizers.

Biosolids do have two important characteristics common to organic fertilizers:

- Their nutrients are released slowly from the organic form by natural processes in the soil.
- They are a product of the waste stream that can benefit crop growth.

Commercial Organic Fertilizers

Many organic by-products and some unprocessed minerals are sold as organic fertilizers. Table 4.8 shows approximate nutrient contents of some of these materials. The numbers represent total nutrient content. Because most are slow-release fertilizers, not all of the nutrients are available the year they are applied.

Table 4.8 shows that most organic fertilizer materials contain one main nutrient. The other nutrients are present in smaller amounts, which means that although organic fertilizers contain a variety of nutrients, they may not be present in the proportions needed by plants. Several companies produce balanced organic fertilizers by blending these materials into a single product that provides all of the primary nutrients in balanced proportions.

Commercial organic fertilizers tend to be more expensive per pound of nutrients than either processed fertilizers or manures. Sometimes the difference in price is substantial. Nevertheless, many gardeners use these products because of convenience. They are most economical for small gardens where little fertilizer is needed.

The cost per pound of nutrients in organic fertilizers varies widely, depending on the type of material, the concentration of nutrients, and the package size. Compare costs and nutrient availability when shopping for organic fertilizers.

Table 4.8. Total nitrogen, phosphate, and potash content of selected organic fertilizers.

Material	Nitrogen (%)	P_2O_5 (%)	K_2O (%)
Cottonseed meal	6–7	2	1
Blood meal[1]	12–15	1	1
Alfalfa	2	0.5	2
Bat guano[1]	10	3	1
Fish meal[1]	10	4	0
Fish emulsion[1]	3–5	1	1
Bone meal	1–4	12–24	0
Rock phosphate[2]	0	25–30	0
Greensand	0	0	3–7
Kelp meal	1	0.1	2–5

[1] Contains a substantial amount of quickly available nitrogen that plants can use early in the season.
[2] Very low P availability (only 2–3%). Useful only in acid soils.

How Much Fertilizer to Use

The goal of applying fertilizer is to supply enough nutrients to meet plant needs without accumulating excess nutrients in the soil that could leach into groundwater or run off into surface water. Soil tests and use of Cooperative Extension publications can help you estimate fertilizer needs.

Soil Tests

A soil test gives information on the levels of nutrients in your soil and recommends how much fertilizer to add each year based on the test results and the crops you grow. You don't need to test your soil every year; every three to five years is enough.

A garden soil test typically includes the nutrients phosphorus, potassium, calcium, magnesium, and zinc. The test also includes soil pH and recommends lime if it's needed to raise pH. In areas with historically high manure applications, a test for soluble salts can be worthwhile.

Soil test labs don't routinely test for nitrogen because there is no simple way to predict nitrogen availability. The lab will give a general nitrogen recommendation, however, based on the plants you are growing and on information you provide about the soil (such as whether there is a history of manure applications, which would increase soil-available nitrogen).

To take a soil sample, first collect subsamples from at least 10 different spots in your garden. Avoid any unusual areas, such as the site of an old trash dump, burn pile, or rabbit hutch. Sample the top six inches of soil (zero to six inches) if the soil has been tilled and zero to four inches for non-tilled soil and lawns. Air-dry the samples and mix them together well. Send about a pint of the mixed sample to your local county Cooperative Extension Service office.

If you're planting different crops but the area has had similar previous fertilizer additions, it's probably not necessary to submit more than one soil sample. Instead, use the fertilizer recommendations for the various crops.

Before choosing a lab, call to make sure it tests and makes recommendations for garden soils. Ask a lab representative the following questions:

- Do you routinely test garden soils for plant nutrients and pH?
- Do you use Kentucky test methods and fertilizer guides?
- Do you give recommendations for garden fertilizer applications?
- Are there forms to fill out? What information do you need?
- How much does a test cost?
- How quickly will you send results?

Cooperative Extension Publications

Soil testing is highly recommended, but if you are unable to submit a sample for testing, you can use Cooperative Extension publications to estimate your needed fertilizer additions. These publications usually give recommendations for processed fertilizers, but some give guidelines for organic fertilizers as well. Kentucky has published fertilizer recommendations for a variety of crops. See "For More Information" at the end of this chapter. Also see other chapters in this series for information on specific crops.

A typical extension recommendation is for two pounds of nitrogen per 1,000 square feet of garden, usually applied in a mixed fertilizer with a 1:0:1 ratio. (Fast-growing crops such as sweet corn need more nitrogen.) Gardens with a history of fertilizer application will most likely not need any phosphorus and will only require a small amount of potassium. You won't know for sure unless you test. Due to the environmental risks associated with excess phosphorus, the University of Kentucky does not recommend any phosphorus fertilizer application unless a soil test is conducted.

Estimating Organic Fertilizer Rates

Estimating how much organic fertilizer to use can be a challenge because you must estimate the availability of nutrients in the fertilizer. Here are some tips:

- Organic fertilizers with large proportions of available nutrients (such as bat guano and fish emulsion) can be substituted for processed fertilizers on a one-to-one basis. Use the same quantity called for in the processed fertilizer recommendation.
- Apply other packaged fertilizers according to their nutrient availability. Composts, rock phosphate, and plant residues generally have lower nutrient availability than more concentrated animal products (for example, blood meal, bone meal, and chicken manure). The recommended application rates on packaged organic fertilizers are a good guideline. Check these recommendations against other products to make sure they seem reasonable.
- Nutrient concentration and availability in farmyard manures vary widely, depending on the type of manure and its age and handling. Application rates range from five gallons per 100-150 square feet for high-nitrogen poultry manure to one to two inches deep for cow or horse manure composted with bedding. Estimate application rates based on the type of manure.
- Observe your crops carefully. Lush plant growth and delayed flowering and fruiting are signs of high amounts of available nitrogen and may indicate overfertilization.
- Experiment with different fertilizer rates in different parts of a row, and see whether you notice differences in crop performance. Plan your experiment carefully so you are confident that differences are the result of different fertilizer rates rather than differences in soil, water, sunlight, or management practices.
- Soil testing is valuable in understanding your soil's nutrient status. Many established gardens have high levels of soil fertility, so that crops grow well with little fertilizer.

How to Calibrate a Fertilizer Spreader by the Volume Method

1. Based on the fertilizer analysis, determine the amount of actual fertilizer that needs to be spread per 1,000 square feet. (To get a rate of 1.5 pounds of nitrogen per 1,000 square feet, 30 pounds of 5-5-5 or 15 pounds of 10-10-10 would be required.)
2. Start with a known amount of fertilizer (for example, a 50-pound bag) and a known volume (for example, two five-gallon buckets of same size).
3. Pour the fertilizer into the buckets and measure the total height, leveled. If the measurement is in inches, there will be a known amount of fertilizer (50 pounds) per so many inches. For example, if 50 pounds measures 31 inches total in the two buckets, 50 pounds/31 inches equals 1.6 pounds per inch of bucket height. This standard calculation will allow determination of a weight if scales are not available.
4. Determine the width of the fertilizer spread pattern, then the total area.

(Known width x distance = total area)

5. Set the spreader's gate to manufacturer's recommendation. Most fertilizers will have a different flow pattern and density, so one factory setting will not work for all fertilizers.
6. Measure a known distance—for example, 50 feet. Apply the fertilizer to the 50-foot line. Do not collect the fertilizer. Pour remaining fertilizer in the spreader back into the bucket, and measure the height. (Remember that for this example, one inch in the bucket weighs 1.6 pounds.)

Example:

With a 10-foot spread width and 50-foot length, total area equals 500 square feet.

For this area, we want 1.5 pounds of nitrogen per 1,000 square feet, or 15 pounds of 10-10-10.

- After spreading 50 feet of fertilizer at a 10-foot width, pour the remaining fertilizer back into the bucket and measure. For this example, let's assume the measurement is seven inches.
- Based on the previous determination of a fertilizer weight of 1.6 pounds per inch, seven inches multiplied by 1.6 pounds per inch equals 11.2 pounds of fertilizer.
- Because calibration is on 500 square feet and the recommendation is for 1,000 square feet, multiply by two, which equals 22.4 pounds of fertilizer per 1,000 square feet.
- Amount of 10-10-10 needed to achieve the 1.5 pounds of nitrogen per acre is 15 pounds and our calculations show that 22.4 pounds was applied; therefore, we are applying too much. We need to reduce the amount coming out of the spreader and calibrate again.
- Continue using this procedure until you have the desired rate.

When to Fertilize

In most cases, the best time to apply fertilizer is close to the time when plants need the nutrients. This timing reduces the potential for nutrients to be lost before they are taken up by plants. Not only is nutrient loss inefficient, it may contaminate groundwater or surface water.

Plants need the largest amount of nutrients when they are growing most rapidly. Rapid growth occurs in midsummer for corn and squash, earlier for spring plantings of lettuce and other greens. Plants also need available nutrients shortly after seeding or transplanting.

For a long-season crop such as corn, many gardeners apply a small amount of fertilizer as a starter at the time of seeding and then add a larger amount in early summer just before the period of rapid growth. When using organic fertilizers, a single application usually is adequate, because nutrient release usually is fastest just before plant demand is greatest.

For perennial plants, timing depends on the plant's growth cycle. Blueberries, for example, benefit most from fertilizer applied early in the season at bud break, while June-bearing strawberries are fertilized after harvest. Refer to other chapters in this manual and to other Extension publications for information on timing fertilizer applications for specific crops.

Adding Organic Matter

Organic matter builds and stabilizes soil structure, thus reducing erosion and improving soil porosity, infiltration, and drainage. It holds water and nutrients for plants and soil organisms. It also is a long-term, slow-release storehouse of nitrogen, phosphorus, and sulfur, which continuously become available as soil microorganisms break down the organic matter.

The value of organic materials varies, depending on their nitrogen content (more specifically, their carbon to nitrogen, or C:N, ratio). Organic materials with a low C:N ratio, such as undiluted manure or blood meal, are rich in nitrogen. They are a good source of nutrients but must be used sparingly to avoid overfertilization.

Materials with an intermediate C:N ratio (including many composts, leaf mulches, and cover crop residues) have lower nutrient availability. They are the best materials to replenish soil organic matter. Because they are relatively low in available nutrients, you can add them to the soil in large amounts.

Materials with a high C:N ratio (such as straw, bark, and sawdust) contain so little nitrogen that they reduce levels of available nitrogen when mixed into the soil. Soil microorganisms use available nitrogen when they break down these materials, leaving little nitrogen for plants. This process is called "immobilization" and results in nitrogen deficiency. If you use materials with a high C:N ratio in your garden, add extra nitrogen fertilizer to compensate for immobilization. The best use for these materials is for mulches around perennial crops or in walkways. They do not cause nitrogen immobilization until you mix them into the soil.

Compost

Compost is an excellent source of organic matter for garden soils. Composting also closes the recycling loop by turning waste materials into a soil amendment. You can make compost at home or buy commercially prepared compost.

Homemade Compost

The key to composting is to supply a balance of air, water, energy materials (materials with a low C:N ratio, such as grass clippings, green garden trimmings, or fresh manure), and bulking agents (materials with a high C:N ratio, such as corn stalks, straw, and woody materials). You don't need additives to stimulate your compost pile. You just need to provide conditions favorable for natural composting organisms.

You can compost in the following ways:

- Hot (fast) composting produces high-quality, finished compost in six to eight weeks. To maintain a hot compost pile, mix together balanced volumes of energy materials and bulking agents, keep the pile moist, and turn it frequently to keep it aerated.
- Cold (slow) composting requires less work than hot composting. Build the pile and leave it until it decomposes. This process may take months or longer. Cold composting does not kill weed seeds or pathogens. Rats and other pests can be attracted to edible wastes in cold compost piles.
- You can compost fruit and vegetable scraps in a worm bin. This method works well for urban gardeners who have little space.
- You can bury fruit and vegetable scraps and allow them to decompose in the soil.

Commercial Compost

Yard debris is the major raw material in most commercial compost sold in Kentucky. Commercial compost also may contain animal manure, biosolids, food waste, or wood waste. Commercial compost is made on a large scale, with frequent aeration and/or turning to create conditions that kill weed seeds, plant pathogens, and human pathogens.

Compost Use

Adding one to two inches of compost each year helps build a productive garden soil. You can till or dig compost directly into your garden or use it as a mulch before turning it into the soil. One cubic yard of compost covers about 325 square feet to one inch deep. In the first year after application, partially decomposed woody compost may immobilize some soil nitrogen, resulting in nitrogen deficiency for plants. If plants show signs of nitrogen deficiency (poor growth or yellow leaves), add extra nitrogen fertilizer (either organic or inorganic). In subsequent years, most compost contributes small amounts of available nitrogen to the soil.

It is important to know the source of composted materials derived from grass clippings or animal manure used as fertilizer amendments on your garden or landscape plants. Herbicide residues could be present that can cause injury to sensitive garden plants such as tomatoes and other broadleaf plants. Active ingredients in certain herbicide products applied to lawns can be retained in grass clippings, or animals consuming herbicide-treated pastures and hay can pass the material through the digestive system, so that the herbicide in the manure persists at concentrations that will cause injury to sensitive crops. Furthermore, the composting process may not fully degrade these herbicide compounds. To be safe, make sure that composted grass clippings and manure used on your garden or landscape areas have not been directly or indirectly exposed to herbicides.

Green Manure (Cover Crops)

Green manures are cover crops grown specifically to be tilled or dug into the soil. Planting green manure is a way to grow your own organic matter. The value of cover crops goes beyond their contribution of organic matter, however. They also can do the following:

- Capture and recycle nutrients that otherwise would be lost by leaching during winter
- Protect the soil surface from rainfall impact
- Reduce runoff and erosion
- Suppress weeds
- Supply nitrogen (legumes only)

Roots from cover crops, especially crops that produce taproots, can penetrate a moderately compacted zone and help distribute nutrients deeper into the soil profile.

No one cover crop provides all of these benefits. Deciding which cover crop or combination to grow depends on which benefits are most important to you and which cover crops best fit into your garden plan (Table 4.9). With the exception of buckwheat, all of the cover crops listed in Table 4.9 are suitable for fall planting and spring tillage.

Table 4.9. Examples of cover crops for Kentucky.

Cover Crop	Characteristics
Annual ryegrass	Hardy, tolerates wet soils, can be difficult to control if seeds
Austrian winter peas	Legume, does not compete well with winter weeds, must establish early fall
Buckwheat	Rapid germination and growth, frost sensitive, drought tolerant
Cereal rye	Hardy, rapid growth, matures rapidly in spring
Crimson clover	Legume, grows more slowly than vetch
Hairy vetch	Legume, slow initial growth, grows quickly in the spring, can be difficult to kill
Winter triticale	Produces more vegetation than cereal rye or winter wheat
Winter wheat	Most common cover crop, covers soil well, matures slowly
Turnip/mustard greens	Grow well in fall, strong taproots to break compacted layers, edible

Note: All legumes fix nitrogen.

Gardeners usually plant cover crops in the fall and till them into the soil before planting in the spring. The earlier cover crops are planted, the more benefits they provide.

Termination time for cover crops can affect nutrient availability for subsequent crops and other management issues. Late termination of a cereal can tie up nitrogen due to the cover crop's high C:N ratio, and early termination of a cover crop can release nitrogen before it is needed, reducing its benefit to the garden.

Legumes such as vetch and crimson clover need an early start to achieve enough growth to cover the soil before cold weather arrives.

If your garden contains crops into November or December, it will not be possible to plant early cover crops over the entire area. In this case, plant cover crops in areas you harvest early and use mulch in those you harvest later. For example, plant a cover crop in a sweet corn bed immediately following harvest in September, and mulch a bed of fall greens after you remove the crop in November. You also can start cover crops between rows of late crops if space allows.

Till or dig cover crops into the soil before they flower. After flowering, plants become woody and decline in quality. Also, digging plants into the soil becomes quite difficult if they grow too large. If you cannot till a cover crop before it blooms, cut it off and compost it for later use. You will still get the short-term benefit of organic matter from the crowns and roots when you till your garden.

The organic matter benefits of cover crops last only about one year, so make cover crops an annual part of your garden rotation. If they do not fit into your garden plan, you can use winter mulches as a substitute.

Soil pH

Soil pH measures the acidity or alkalinity of a soil. At a pH of 7 (neutral), acidity and alkalinity are balanced. Acidity increases by a factor of 10 with each one-unit drop in pH below 7. For example, a pH of 5.5 is 10 times as acidic as a pH of 6.5. Alkalinity increases by a factor of 10 with each one-unit change in pH above 7.

Native soil pH depends on the minerals present in the soil and on rainfall. Soils in arid areas tend to be alkaline, and those in rainy areas tend to be acid. Gardening and farming also affect soil pH; for example, many nitrogen fertilizers tend to reduce pH, while liming increases pH.

Soil pH influences plant growth in three ways, affecting the following:

- availability of plant nutrients (Figure 4.8)
- availability of toxic metals
- activity of soil microorganisms, which in turn affects nutrient cycling and disease risk

The availability of phosphorus decreases in acid soils, while the availability of iron increases. In alkaline soils, the availability of iron and zinc can be quite low.

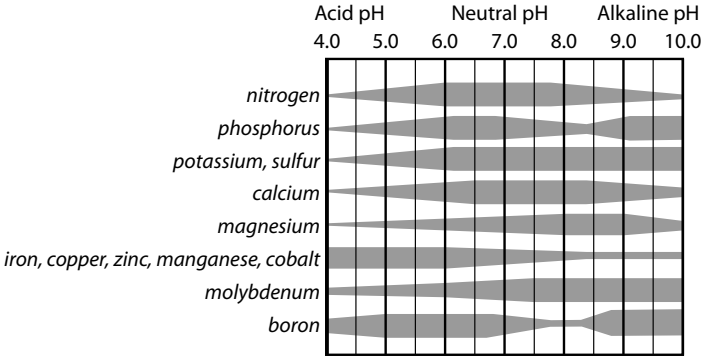

Figure 4.8. Effect of soil pH on the availability of plant nutrients.

Aluminum availability increases in acid soils. Aluminum is one of the most common elements in soil, but it is not a plant nutrient and is toxic to plants in high concentrations. Very little aluminum is in solution in soils above pH 6, and what is present causes no problems for plants. As pH declines and aluminum availability increases, aluminum toxicity can become a problem.

Microbes also are affected by soil pH. The most numerous and diverse microbial populations exist in the middle of the pH range. Fewer organisms are adapted to strongly acid or strongly alkaline soils. Nutrient cycling is slower in acid and alkaline soils because of reduced microbial populations.

Many garden crops perform best in soil with pH of 5.5 to 7.5, but some (such as blueberries and rhododendrons) are adapted to more strongly acidic soils. Before amending soil to adjust pH, it is important to know the preferred pH ranges of your plants.

Increasing Soil pH

The most common way to increase soil pH is to add lime, which is ground limestone, a rock containing calcium carbonate. It is an organic (natural) amendment, suitable for use by organic gardeners.

Lime raises the pH of acid soils and supplies calcium, an essential nutrient. Dolomitic lime contains magnesium as well as calcium.

The best way to determine whether your soil needs lime is to have it tested. Do not lime areas where you grow acid-loving plants, because they are adapted to acid soils.

Lime is a slow-release material. Apply it in the fall to benefit spring crops.

Wood ashes are a readily available source of potassium, calcium, and magnesium. Like lime, they also raise soil pH. High rates of wood ashes may cause short-term salt injury, so apply less than 15 to 25 pounds per 1,000 square feet. We do not recommend using wood ashes in alkaline soils.

Gypsum (calcium sulfate) is not a substitute for lime. It supplies calcium and sulfur, but has little effect on soil pH. Gypsum has been promoted as a soil amendment to improve soil structure. In the vast majority of cases, it does not work. Gypsum improves structure only when poor structure results from excess sodium in the soil, a rare condition in Kentucky.

Use organic amendments to improve soil structure, as described earlier under "Adding Organic Matter."

Some composts can increase soil pH, as can poultry litter, due to diet and amendments added to bedding material.

Decreasing Soil pH

You may need to decrease soil pH if you wish to grow acid-loving plants. Elemental sulfur and aluminum sulfate lower soil pH. Soil testing is the best way to determine whether sulfur is needed, and if so, how much. Refer to Table 4.10 to determine the amount of sulfur needed when lowering soil pH.

Ammonium sulfate fertilizer also lowers pH, but it takes longer than sulfur to have an effect. All nitrogen fertilizers that contain ammonium (NH_4^+) also reduce pH slowly.

Table 4.10. Materials required to lower soil pH to specific levels. Use the following table for each 100 sq ft.[1] Multiply by 436 for lb/A.

To Change pH from:	Add		
	Wettable Sulfur (lb)	or	Aluminum[3] Sulfate (lb)
8.0 to 7.0	2		3.0
8.0 to 6.5	3		4.5
8.0 to 6.0	4		6.0[2]
8.0 to 5.5	5		7.5[2]
8.0 to 5.0	6		9.0[2]
7.5 to 7.0	1		1.5
7.5 to 6.5	2		3.0
7.5 to 6.0	3		4.5
7.5 to 5.5	4		6.0[2]
7.5 to 5.0	5		7.5[2]
7.5 to 4.5	6		9.0[2]
7.0 to 6.5	1		1.5
7.0 to 6.0	2		3.0
7.0 to 5.5	3		4.5
7.0 to 5.0	4		6.0[2]
7.0 to 4.5	5		7.5[2]
6.5 to 6.0	1		1.5
6.5 to 5.5	2		3.0
6.5 to 5.0	3		4.5
6.5 to 4.5	4		6.0[2]
6.0 to 5.5	1		1.5
6.0 to 5.0	2		3.0
6.0 to 4.5	3		4.5
5.5 to 5.0	1		1.5
5.5 to 4.5	2		3.0
5.0 to 4.5	1		1.5

[1] Aluminum sulfate is faster in reaction than sulfur. The two materials may be applied together (half of each). Incorporate into the top 6 inches of the soil.
[2] Rates higher than 4.5 lb per 100 sq ft can cause excess soluble salt problems. Split the amount in half and apply in the spring and fall.
[3] Aluminum sulfate is less effective in reducing soil pH but is quicker acting than wettable sulfur. More frequent applications may be necessary.

Prepared by Kathy Keeney, McCracken County extension agent for horticulture.

Soils and Fertilizer Terminology

Aggregation—The process by which individual particles of sand, silt, and clay cluster and bind together to form peds.

Anion—A negatively charged ion. Plant nutrient examples include nitrate (NO^-_3), phosphate ($H_2PO_4^-$), and sulfate (SO_4^{2-}).

Aspect—Direction of exposure to sunlight.

Biosolids—A by-product of wastewater treatment sometimes used as a fertilizer.

Capillary force—The action by which water molecules bind to the surfaces of soil particles and to each other, thus holding water in fine pores against the force of gravity.

Cation—A positively charged ion. Plant nutrient examples include calcium (Ca^{2+}) and potassium (K^+).

Cation exchange capacity (CEC)—A soil's capacity to hold cations as a storehouse of reserve nutrients.

Clay—The smallest type of soil particle (less than 0.002 millimeters in diameter).

C:N ratio—The ratio of carbon to nitrogen in organic materials. Materials with a high C:N ratio are good bulking agents in compost piles, while those with a low C:N ratio are good energy sources.

Cold composting—A slow composting process of simply building a pile and leaving it until it decomposes. This process may take months or longer. Cold composting does not kill weed seeds or pathogens.

Compaction—Pressure that squeezes soil into layers that resist root penetration and water movement. Often the result of foot or machine traffic or tilling when the soil is too wet.

Compost—The product created by the breakdown of organic materials under conditions manipulated by humans.

Cover crop—A crop planted in the offseason to reduce soil loss and capture nutrients not used during the growing season. Called a green manure when planted with the intention of incorporating into the soil.

Decomposition—The breakdown of organic materials by microorganisms.

Fertilizer—A natural or synthetic product added to the soil to supply plant nutrients.

Fertilizer analysis—The amount of nitrogen, phosphorus (as P_2O_5), and potassium (as K_2O) in a fertilizer, expressed as a percent of total fertilizer weight. Nitrogen (N) always is listed first, phosphorus (P) second, and potassium (K) third.

Green manure—See *Cover crop*.

Hot composting—A fast composting process that produces finished compost in six to eight weeks. High temperatures are maintained by mixing balanced volumes of energy materials and bulking agents, keeping the pile moist, and turning it frequently to keep it aerated.

Humus—The stable end product of decomposed animal and plant remains of unrecognizable origin, their partial decomposition products, and waste for soil biomass. Same as soil organic matter.

Immobilization—The process by which soil microorganisms use available nitrogen as they break down materials with a high C:N ratio, thus reducing the amount of nitrogen available to plants.

Infiltration—The movement of water into soil.

Ion—An atom or molecule with either positive or negative charges.

Leaching—Movement of water and soluble nutrients down through the soil profile.

Loam—A soil with roughly equal influence from sand, silt, and clay particles.

Macropore—A large soil pore. Macropores control a soil's permeability and aeration and include earthworm and root channels.

Micronutrient—A nutrient used by plants in small amounts (iron, zinc, molybdenum, manganese, boron, copper, and chlorine). Also called a trace element.

Micropore—A fine soil pore, typically a fraction of a millimeter in diameter. Micropores are responsible for a soil's ability to hold water.

Mycorrhizae—Beneficial fungi that infect plant roots and increase the plants' ability to take up nutrients from the soil, particularly phosphorus.

Nitrifier—A microbe that converts ammonium to nitrate.

Nitrogen cycle—The sequence of biochemical changes undergone by nitrogen as it moves from living organisms to decomposing organic matter, to inorganic forms, and back to living organisms.

Nitrogen fixation—The conversion of atmospheric nitrogen into plant-available forms by Rhizobia bacteria.

Organic fertilizer—A natural fertilizer material that has undergone little or no processing. Can include plant, animal, and/or mineral materials.

Organic materials—Recognizable materials originating from living organisms, the precursors to soil organic matter.

Organic matter—Plant remains of unrecognizable origin, their partial decomposition products, and waste for soil biomass. See *Humus*.

Pathogen—A disease-causing organism. Pathogenic soil organisms include bacteria, viruses, fungi, and nematodes.

Ped—A cluster of individual soil particles.

Permeability—The rate at which water moves through a soil.

pH—A measure of acidity or alkalinity. Values from 0 to 7 indicate acidity, a value of 7 is neutral, and values from 7 to 14 indicate alkalinity. Most soils have a pH between 4.5 and 9.

Phosphate—The form of phosphorus listed in most fertilizer analyses (P_20_5).

Potash—The form of potassium listed in most fertilizer analyses (K_20).

Primary nutrient—A nutrient required by plants in a relatively large amount (nitrogen, phosphorus, and potassium). See *Macronutrient*.

Processed fertilizer—A fertilizer that is manufactured or is refined from natural ingredients to be more concentrated and more available to plants.

Quick-release fertilizer—A fertilizer that contains nutrients in plant-available forms such as ammonium and nitrate.

Rhizobia bacteria—Bacteria that live in association with roots of legumes and convert atmospheric nitrogen to plant-available forms, a process known as nitrogen fixation.

Rhizosphere—The thin layer of soil immediately surrounding plant roots.

Sand—The coarsest type of soil particle (0.05 to 2 millimeters in diameter).

Secondary nutrient—A nutrient needed by plants in a moderate amount (sulfur, calcium, and magnesium).

Silt—A type of soil particle that is intermediate in size between sand and clay (0.002 to 0.05 millimeters in diameter).

Slow-release fertilizer—A fertilizer that is not immediately available for plant use after application. This can be a processed fertilizer that has a coating or additive or a type that must be converted into a plant-available form before being utilized.

Soil—A natural, biologically active mixture of weathered rock fragments and organic matter at the earth's surface.

Soil salinity—A measure of the total soluble salts in a soil.

Soil solution—The solution of water and dissolved minerals found in soil pores.

Soil structure—The arrangement of aggregates (peds) in a soil.

Soil texture—How coarse or fine a soil is. Texture is determined by the proportions of sand, silt, and clay in the soil.

Soluble salt—A compound often remaining in soil from irrigation water, fertilizer, compost, or manure applications.

Water-holding capacity—The ability of a soil's micropores to hold water for plant use.

For More Information

For more information, contact your county Extension agent.

University of Kentucky Cooperative Extension Service Publications

Home Composting: A Guide to Managing Home Yard Waste (HO-75)
Home Vegetable Gardening (ID-128)
Lime and Fertilizer Recommendations (AGR-1)
Organic Manures and Fertilizers for Vegetable Crops (https://www.uky.edu/hort/sites/www.uky.edu.hort/files/documents/organicmanures.pdf)
Water Quality and Nutrient Management at Home (HENV-402)
Winter Cover Crops for Kentucky Gardens and Fields (ID-113)

Other Resources

Bohn, H.L., B.L. McNeal, and G.A. O'Connor. *Soil Chemistry, 3rd edition* (John Wiley & Sons, New York, 2001).
Brady, N.C., and R.R. Weil. *The Nature and Properties of Soils, 14th edition* (Prentice-Hall, New York, 2007).
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Donahue, R.L., R.W. Miller, and J.C. Shickluna. *Soils: An Introduction to Soils and Plant Growth* (Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1990).
Tisdale, S.L., and W.L. Nelson. *Soil Fertility and Fertilizers* (Macmillan Publishing Co., Inc., New York, 1985).

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High Tunnel Soil Management for Season Extension

January 2, 2024 / in Blog, Crops

By Chris Lent [https://attra.ncat.org/christopher-lent/] , NCAT Agriculture Specialist

When I began to see how unique the growing conditions in my high tunnel are compared to open-field growing, I started to think differently about how to maintain soil health and manage soil fertility for high tunnel growing and season extension. Soil fertility is the soil's capacity to hold essential nutrients and make them available to plants through a combination of chemical, physical, and biological conditions in the soil. The conditions created inside a high tunnel can affect soil health and fertility in unique ways. In this installment in my blog series on high tunnel season extension, I'll talk about approaches to managing soil health and fertility.

When you step into a high tunnel, you're moving off your farm in terms of temperature, humidity, and frost dates. Higher temperatures can speed crop growth and increase demands on the soil. Close plant spacings, quick crop successions, and extended seasons, typical in tunnel production, add to those demands. With increased crop successions comes increased soil preparation and tillage that can impact soil structure. At the same time, increased biological activity caused by warmer soils for more of the year can accelerate the breakdown of organic matter releasing nutrients and also deplete soil organic matter (SOM) levels. Salts from added compost, manure, or fertilizers can build up in the rain-free environment of a tunnel and accumulate near the soil surface, affecting crop growth. And because tunnel crops are entirely dependent on irrigation water, elevated alkalinity, iron, sodium, or chloride in the water can cause problems in the soil, as well.

There are several ways to overcome these soil health and fertility challenges, and autumn is a good time to start work on strategies for the extended season and to prepare for the following spring. These strategies start with soil testing. Testing around the same time each year will allow a fair comparison of any changes in the soil from test to test. In addition to a standard nutrient test that shows nutrient and pH levels, organic matter content and soluble salt levels should be tested. Based on the test results and crop

enough to affect crop growth can be flushed with rainwater by leaving the plastic off the tunnel when installing new plastic or through irrigation. Twelve to 24 inches of water can flush 80% to 90% of the soluble salts from the soil. Irrigation water should be tested for excess salt and other nutrients and should be treated or filtered as needed. If compost is used as a soil amendment, using vegetation-based compost instead of composted animal manure can reduce the possibility of salt build-up in the soil.

High tunnel kale crop for harvest through the fall. Photo: Chris Lent, NCAT

High organic matter content is good for the soil and can benefit soil fertility… right? Yes, but SOM levels can be hard to maintain in a high tunnel. Many growers turn to compost to amend the soil and help raise SOM. Testing your source of compost for nutrient levels and soluble salt levels is a good idea to be sure it's not contributing to problems in the soil. Cover crops, which I talk about below, are another good tool to increase SOM.

There has been much more research on the fertility needs of high-value, warm-season tunnel crops, like tomatoes, than on cool-season greens. But a few studies have indicated that increasing amounts of nitrogen fertilizer has little effect on yield in cool-season tunnel greens production. This is probably because most cool-season greens have a lower nitrogen requirement and there is enough left in the soil from what was supplied to summer crops. Secondly, we know that for each percent of organic matter above 2%, a nitrogen credit of about 20 pounds per acre can be considered before applying nitrogen fertilizer for a crop. For many fall and winter crops, this means no additional nitrogen is needed at all. Another good reason to be careful with nitrogen applications is that excess nitrogen in the soil has been linked to increased aphid populations in cool-weather greens production.

Cover crops can help improve most soil-related issues in high tunnels. As I already said, they increase organic matter and improve soil structure, and leguminous covers can add nitrogen to the soil for the next crop without increasing salinity. Cover crops can also help break some pest and disease cycles. But it's difficult for growers to sacrifice valuable high tunnel space for a non-cash crop. The timing of a cover crop and the type of cover used will vary by region, but the technique of under sowing a cover crop in warm-season tunnel crops like tomatoes or cucumbers can be a good strategy to prepare for fall and winter greens production. Another window to plant cover crops in a high tunnel is in the spring

when winter greens harvest is slowing. Spring-planted covers won't fully develop before summer crops should be planted, but they can still contribute to soil health.

Planted at the start of September this fast-growing buckwheat was starting to flower by mid-October in the author's high tunnel. Photo: Chris Lent, NCAT

Because of the numerous benefits to the soil that cover crops provide, some growers have opted to take a tunnel or a portion of one out of cash crop production for part of the season to plant cover crops.

More growers are trying reduced tillage techniques to protect the health and structure of their soil. Options here include shallow soil tillage (top 1 to 2 inches), no-till transplanting through a layer of compost or mulch, no-till transplanting through a winter-killed or crimp-killed cover crop, or the use of plastic tarps to control weeds and condition the soil before being removed to plant a crop. All these techniques are applicable to high tunnel growing and can be used to improve soil function by protecting the porosity and structure of the soil.

Growers who are using tunnels for main season and extended season growing are asking a lot of their soil. Regular soil and irrigation water testing, along with knowing nutrient levels in compost and other amendments, will help with balancing fertility to avoid issues. Cover crops used well can be very effective at improving and maintaining soil conditions. And reduced tillage techniques can also help overworked soils. With a combination of these approaches, high tunnel soils can be sustained for year-round crop production.

Related ATTRA Resources:

Season Extension Techniques for Market Gardeners [/publication/season-extension-techniques-for-market-gardeners/]

Sustainable Season Extension: Considerations for Design [/publication/sustainable-season-extension-considerations-for-design/]

Purchasing and Siting a High Tunnel to Extend the Growing Season [/purchasing-and-siting-a-high-tunnel-to-extend-the-growing-season/]

Organic Greenhouse Vegetable Production [/publication/organic-greenhouse-vegetable-production/]

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Tags: Cover Crops, High Tunnel, Season Extension, Soil

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October 2019 Horticulture/Soils/2019-01pr

Sustainable Manure and Compost Application: Garden and Micro Farm Guidelines

Melanie Stock, Tiffany Maughan, and ***Rhonda Miller***

Applying animal manure and compost to the soil is a long-standing practice for farmers across the world. When properly managed, animal manures increase soil fertility, build soil organic matter, and sustainably cycle nutrients. However, knowing how much and when to apply manure is critical for long-term soil heath. This fact sheet provides general information on manure and compost characteristics and a step-by-step example for calculating application rates that are appropriate for gardens and micro farms (<5 acres).

Plant Nutrient Basics

There are 14 mineral nutrients that are essential for plant growth. Six of the nutrients are classified as **macronutrients** because plants need these nutrients in greater amounts, and eight are **micronutrients** because plants only need trace amounts. Plant yields will decrease if the soil does not have sufficient levels of each nutrient. The three most important macronutrients to manage are the **primary macronutrients**: nitrogen (N), phosphorus (P), and potassium (K). To ensure optimal plant growth, N generally needs to be added each year to non-legume crops to improve or maintain yield. P and K can accumulate in Utah soils, so it is important to regularly soil test to see if additions are needed. The **secondary macronutrients** are calcium (Ca), magnesium (Mg), and sulfur (S). The **micronutrients** are boron (B), cobalt (Co), copper (Cu), iron (Fe), chlorine (Cl), manganese (Mn), molybdenum (Mo) and zinc (Zn). Most Utah soils have sufficiently high (and sometimes excessively high) levels of secondary macronutrients and sufficient micronutrients to support healthy plant growth. Therefore, these nutrients often do not require regular soil testing or application. For more information on nutrient types, reference USU Extension Master Gardener Chapter, Fertilizers.

Manure as a Soil Builder and Nutrient Source

Manures contain most, or all, of the 14 soil-derived plant mineral nutrients, as well as organic matter. Organic matter is decomposed plant and animal tissue that will coat soil particles to give topsoil its rich, dark color. Increasing the amount of organic matter in the soil through manure or compost application can improve soil health and productivity by:

- increasing nutrients available to plants and nutrient storage in the soil,
- increasing the water available to plants and water storage in the soil,
- improving soil structure, which promotes aeration and drainage,
- supporting soil microbial communities,
- reducing compaction and surface crusting, and
- reducing erosion.

This is important in Utah, where the native soil organic matter is low (0.50 – 2%) because of the semi-arid climate. Increasing organic matter to around 5% is ideal for many soils and crops. Incorporating manure and compost into the soil is an excellent way to build soil organic matter while managing soil fertility for optimum plant growth. Manures high in undigested material or large amounts of non-sand bedding material (straw, wood shavings, etc.) will break down slowly over time and add organic matter

to the soil. Solid and semi-solid manures (<75% water content) and composts contain more organic matter and are generally more effective soil builders than liquid manures and slurries (>75% water content). Manures are also readily composted because they have relatively low carbon to nitrogen (C:N) ratios that allow for quick composting. This fact sheet will focus on solid manures and composts that are most common in urban, garden, and micro farm settings.

Figure 1. Manure mixed with high percentage of straw bedding material.

Manure and Compost Application Drawbacks

With the benefits of animal manure application, it can be tempting to apply as much manure or composted manure as possible, particularly when large volumes are available. However, over-application (large quantities or too frequent) and poorly timed applications can result in high soil salinity levels, crop burn, poor plant growth, and environmental contamination. To ensure long-term sustainability, there are key management considerations to follow *that are especially important for Utah soils*. In particular, manure often contains more P and K than needed by crops, but not enough N. This can lead to build up of the P and K in the soil. Too much P can reduce the plant's ability to take up micronutrients from the soil, like Zn, but it also can become an environmental contaminant by polluting surface waters when spring runoff occurs. Too much K can increase soil salinity, which can reduce plant growth and yield. The pH and salinity of manure also tend to be greater than other soil amendments, especially manure from certain livestock like poultry (Table 1). It is important to be aware of the pH and salinity effects that come with manure application because Utah soils tend to already be alkaline (have a high pH for plant growth) and easily accumulate salt. Further increases in the soil pH and salinity through application of manures or composted manures can reduce crop yields, particularly vegetables, fruits, and cut flowers. As a general rule of thumb, these crops start to decline when soils reach a pH greater than 8 and salinity levels greater than 2 dS/m.

Table 1. Average manure characteristics by animal type. The nutrient contents are expressed as percent Nitrogen (N), Phosphate (P2O5), and Potash (K2O). The pH salinity, moisture content, and C:N ratio are also given. The data were collected from the Utah State University Analytical Laboratory (USUAL) from 2005 – 2019.

Solid Manure Type	N	P_2O_5	K_2O	pH	Salinity [dS/m]	Moisture Content [%]	C:N
	-------- % --------						
Alpaca*	0.4	0.3	0.6	8.3	11	77	22
Beef	0.9	0.6	1.1	8.3	8	53	13
Biosolids	2.6	2.0	0.2	7.1	6	45	4
Chicken	2.0	2.7	1.4	8.0	16	46	8
Dairy	0.8	0.5	1.2	8.0	10	68	15
Deer*	1.3	0.6	0.0	7.5	1	28	27
Goat	0.4	0.5	0.1	8.3	1	64	31
Horse	0.7	0.4	1.1	8.7	3	40	17
Llama*	0.5	0.4	0.7	8.6	6	23	21
Mink	1.7	4.8	0.5	7.6	6	38	10
Rabbit*	2.3	1.1	0.4	7.6	1	40	10
Sheep	1.0	0.5	1.0	8.3	7	53	25
Turkey	3.1	2.9	1.7	7.7	10	28	9

*Average based on three or fewer samples.

Raw manure also poses health risks for crops grown for human consumption. Raw manure can harbor unsafe pathogens such as *E. coli*, *Listeria* and *Salmonella*. The USDA's National Organic Program's standard is to apply raw manure at least 120 days before the harvest of crops that come in contact with the soil (carrots, onions, potatoes) and 90 days for crops that do not contact the soil (strawberries, tomatoes, peppers). It is critical for growers to vigilantly follow food-safety practices and carefully plan application timing to reduce the risk of crop contamination. Balancing soil and crop nutrient requirements, building organic matter, meeting manure disposal needs, monitoring soil pH and salinity levels, and being mindful of food safety is key to sustainable land management with manure.

Figure 2. Chicken manure on pine shavings. Note that urine (white substance) is part of bird manure and contributes to high salinity. Photo credit: Melanie Stock.

How Much Manure Should I Actually Apply?

Knowing how much manure to apply depends on how much N, P, and K are in the manure, what crops will be planted, and the nutrient status of the soil, as determined by a soil test. Manure nutrient contents vary by:

- type of animal,
- feeding program,
- amount of bedding mixed in the manure,
- manure age and prior storage, and
- water content of the manure and whether the manure will be incorporated immediately into the soil or not (e.g. tilled into the soil at application or broadcast onto the surface)

Because manure varies widely and changes with the many factors listed, manure or compost should be tested for the best accuracy. USU's Analytical Laboratory tests manure and compost and provides information on proper sample collection and test pricing. To provide an estimate of manure content in Utah, we analyzed all of the manure samples sent to

Figure 3. Collecting manure (deer) for manure testing. Photo credit: Melanie Stock.

the Utah State University Analytical Laboratory from 2005 – 2019. Table 1 lists the expected N, P, and K contents, pH, salinity, moisture, and C:N ratio.

The timing of the manure application is also important to consider because not all of the nutrients, particularly N, are available for plants to use right away. N in animal manures comes in both organic and inorganic forms. The organic form can be thought of as a 'slow release' fertilizer - gradually decomposing and providing plant-available N over time, whereas the inorganic forms are readily available for plant use. Because of this, N from manure should be credited up to three years after an application. When considering the total amount of N in manure, approximately half of N will be available during the first year if the manure is immediately incorporated into the soil. When manure is left on the soil surface, only about 30% of N in manure may be available to plants in the first year. In the second year, about 10% of the remaining nitrogen is available, and about 5% is available in the third year.

On the other hand, most P and K in manure are available to the crop in the first year. It is important to note that in most cases, *manure contains more P and K than is removed by crops and not enough N. Therefore, if the manure is applied at a rate that meets crop N needs, soil P and K can become excessively high.* As mentioned before, too much P is considered an environmental hazard and too much K needlessly increases soil salinity, which can be costly to correct later on.

The best practice to avoid this issue is to apply manure to meet the P needs of the crop. If the manure application does not supply enough N, you will need to supplement with a high N, low P and K fertilizer or amendments (for example: urea, blood meal, feather

meal, fish emulsion, etc.); rotate with legume crops (beans, peas); or plant leguminous cover crops (birdsfoot trefoil, hairy vetch, medics). The worksheet at the end of this fact sheet (page 6) is a step-by-step guide that helps determine how much manure can be sustainably added to your soil and whether additional N will be needed. This fact sheet has a companion fillable workbook that will automatically calculate sustainable rates for your soil.

Figure 4. Backyard compost pile with manure and plant components. Photo credit: Melanie Stock.

Composting Manure before Application

Another option for sustainable animal manure use is to first compost the manure. Composted manure can be one of the best sources of organic matter for your soil. Manure will compost quickly when the compost is frequently turned, adequate moisture levels are maintained, and other compostable materials are added. See USU's composting fact sheet for more information on composting techniques. The benefits of composting manure include: reduced potential to burn crops, reduced odor and flies, the ability to quickly process other garden and farm wastes (such as weeds, raw food scraps, leaf litter, non-sand bedding), and reduced manure volume (by 20-40%) that simplifies transportation and incorporation.

Composting manure prior to application can also serve as an effective storage method, allowing you to have full control of optimally timing applications to the soil. When composting manure, it is important to keep in mind that some N will be lost in the composting process, whereas P and K generally remain. Also, as composting consolidates the material, the pH and salinity of manure-based composts can be greater in the finished product. This must be a consideration when applying compost to soils, as compost can contribute to excessively high soil salinity levels. Plant-based composts, and composts that exclude urine, tend to be lower-salt options.

As a general rule of thumb, about 1 inch of compost can be sustainably added to most Utah soils each year. More may be added depending on your compost source and soil test. Reduce compost use, particularly manure-derived compost, if your soil test shows elevated levels of P, K, and salinity. Here, we provide an estimate of Utah compost characteristics based on analysis of compost samples sent to the Utah State University Analytical Laboratory from 2005 – 2019. Table 2 (next page) lists the expected N, P, and K contents, pH, salinity, moisture content, and C:N ratio.

Figure 5. Compost ready to spread and incorporate into a garden. Photo credit: Tiffany Maughan.

Sustainability Considerations

Incorporating manures and composts into gardens and agricultural fields reduces waste, recycles nutrients back on the landscape, and can improve soil health. When homeowners or growers do not raise animals, manure or compost can usually be locally sourced. Long-term, sustainable applications of manure and manure-based composts depend on the soil fertility

Table 2. Average **compost** characteristics. The nutrient contents are expressed as percent Nitrogen (N), Phosphate (P_2O_5), and Potash (K_2O). The pH, salinity, percent dry matter (%), and C:N are also given. The data were collected from the Utah State University Analytical Laboratory (USUAL) from 2005 – 2019.

Compost Type		N	P_2O_5	K_2O	pH	Salinity [dS/m]	Moisture Content [%]	C:N
		---------- % ----------						
Manure-Based	Beef	1.1	0.9	1.3	8.5	4	28	12
	Chicken	1.4	5.8	2.8	8.2	16	33	17
	Dairy	1.0	0.7	1.5	8.5	8	39	12
	Goat	1.0	0.9	1.9	8.4	5	54	10
	Horse	0.7	0.3	0.9	8.6	4	37	28
	Mink	1.1	3.0	0.3	6.4	6	41	8
	Sheep	1.0	1.1	1.3	8.0	3	39	15
	Turkey	2.2	5.3	2.2	8.2	11	89	10
Other	Biosolids	1.8	1.5	0.2	6.9	5	43	7
	Commercial	1.3	0.9	1.0	7.8	5	35	17
	Municipal	1.2	1.1	0.7	7.8	5	38	17
	Plant-Based	1.4	0.9	0.9	7.9	3	33	16

levels of a garden or field through a soil test, as well as understanding the nutrient, pH, and salinity levels of the manure or compost to be applied. Over-application can lead to excess nutrients that reduce crop growth, contaminate water sources, and create soil salinity issues that are difficult or costly to reclaim. You may have noticed that cat and dog manure and composts were not listed. Those manures should be discarded in the trash. Adding cat or dog manure to the garden or compost attracts undesirable animals (raccoons, rats, mice, snakes), elevates the risk of pathogen exposure, and readily releases bad odors during decomposition.

Conclusion

With mindful application, manure is a great nutrient source with many secondary benefits. Remember to make applications based on P needs to avoid P and K buildup in the soil, and keep in mind that manures also affect soil salinity and pH. The nutrient values provided in Tables 1 and 2 are averages and it is important to recognize that individual sources vary widely. Consider testing any manure or compost you plan to use to know its specific characteristics.

Additional Resources

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NRSC. 2008. Agricultural Waste Management Field Handbook. Chapter 4: Agricultural Waste Characteristics. p. 4-5. United States Department of Agriculture, Natural Resources Conservation Service Part 651. https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=31475.wba

USDA's National Organic Program. 2018. National Organic Program. https://www.ams.usda.gov/

University of California, Inyo-Mono Master Gardener Program. How to Calculate the Carbon-to-Nitrogen Ratio of Your Compost Mix. https://ucanr.edu/sites/mginyomono/files/170818.pdf

MANURE APPLICATION RATE CALCULATION WORKSHEET

1) Garden/Field Information	*Example*		Your Garden:	
Size of garden or field in square feet (length x width)	*500*	*ft^2*		ft^2
2) Soil Test Information				
Soil Nitrogen recommendation (lb/1000 sq. ft):	*4*	*lb/1000 ft^2*		lb/1000 ft^2
Soil Phosphorus (P_2O_5) recommendation (lb/1000 sq. ft):	*2*	*lb/1000 ft^2*		lb/1000 ft^2
Soil Potassium recommendation (lb/1000 sq. ft):	*1*	*lb/1000 ft^2*		lb/1000 ft^2
Divide Soil P_2O_5 by 1000	*0.002*	*lb P_2O_5/ft^2*		lb P_2O_5/ft^2
3) Manure Test Information or Estimate from Table 1				
Manure Nitrogen content (%N):	*2*	*% N*		% N
Manure Phosphorus content (%P_2O_5):	*2.7*	*% P_2O_5*		% P_2O_5
Manure Potassium content (%K_2O):	*1.4*	*% K_2O*		% K_2O
Divide Manure %P_2O_5 by 100	*0.027*	*lb P_2O_5/ lb manure*		lb P_2O_5/ lb manure
Manure Application Amount				
Step 1: Divide dark green box by dark yellow box	*0.074*	*lb manure/ft^2*		lb manure/ft^2
Step 2: Multiply dark blue box by garden size (gray box)	***37.0***	***lb manure to add***		**lb manure to add**

Use our companion Excel Workbook to calculate your Manure/Compost Application rate in just three simple steps.

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USDA U.S. Department of Agriculture Risk Management Agency

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Center for Crop Diversification System Profile
CCD-SP-16

Covers Under Cover: Managing Cover Crops in High Tunnels

Tim Coolong[1], Julia Gaskin[1], Erin Haramoto[2], Krista Jacobsen[2], Jenny Moore[3], Tim Phillips[2], Rachel Rudolph[2], and Annette Wszelaki[3]

High Tunnels: Intensively Cropped, Irrigated Deserts

High tunnels (HTs) are unheated, plastic-covered structures in which temperature is passively controlled by opening and closing the plastic covering on the sides and/or ends of the structure. Crops are generally grown in soil, rather than in pots or growing media. High tunnels can extend the growing season by a month in the fall and spring for warm-season crops, and allow for year-round production of some cool-season crops. High tunnels have been growing in popularity in the Southeastern U.S. due to cost-share programs like the Natural Resource Conservation Service's Environmental Quality Incentives Program (NRCS EQIP) Seasonal High Tunnel Initiative, as well as state specific programs. They have great potential to increase production of local foods and producer profitability by allowing for year-round production in the Southeastern U.S.; however, due to the intensive cropping practices in HTs, problems may arise over time. Because the soil in HTs is not exposed to leaching rains, salts and phosphorus may accumulate, resulting in desert-like soils (Fig. 1). Lack of rain exposure also means that irrigation is required to satisfy all demands for crop growth and for decomposition of crop residues. While fall and spring warming is beneficial, HTs experience more temperature extremes compared to the field. A HT may become quite warm on a cold, sunny winter day, but once the sun goes down the inside temperature of a HT may be very similar to the outside temperature. There is little to no heat retention. The warmer environment in a HT causes faster rates of organic matter breakdown and nutrient mineralization in the soil. Also, this warmer environment speeds up crop growth, potentially worsening nutrient deficiencies. These problems often build up over years and crop productivity may decline. Because of intensive tillage often employed in HTs, breakdown of soil structure and organic matter are often exacerbated compared to in-field production. Due to all of these reasons, if soil health is not maintained in HTs, production in soil can decline enough that producers may need to move the structures or switch to container production, such as "bag culture" systems.

Figure 1. Soil salinity impacts on tomato crop. Notice the much smaller plants in the front of the picture where sodium content is 10 times greater than the back of the picture. The greater sodium content indicates an accumulation of salts in the soil.

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Table 1. Potential benefits and challenges of using cover crops in high tunnels.

Benefits	Challenges
• Provide nitrogen (legumes)	• Availability of equipment that can be used in HTs to terminate cover crop
• Suppress weeds	• Residue management to promote decomposition
• Disrupt disease cycles	• Time and space lost to valuable cash crop production
• Suppress plant-parasitic nematodes	• May provide habitat for insect or other pests, such as plant-parasitic nematodes
• Increase soil organic matter and microbial diversity	
• Improve soil texture and drainage; reduce compaction	
• May have biofumigation potential	

Cover Crops for Productive Rotations: Benefits and Challenge

In field settings, the numerous benefits of cover crops have been well studied. Several years of cover crop use may help alleviate some of the specific problems that arise in HT production. However, the unique conditions in HTs can make the use of cover crops challenging (Table 1). First, irrigation is required to germinate and grow the cover crop. Assuming successful establishment and adequate irrigation, cover crops often accumulate more biomass in the HTs than in the field because of warmer temperatures. Thus, termination of the cover crop can be more difficult in HTs than in the field as the necessary equipment may not fit in the tunnels. After termination, irrigation is needed again to allow the residue to decompose. Also, the timing of cover crops in HTs can be even more difficult than in the field due to the potential loss of revenue when taking the "high value real estate" of HTs out of cash crop production. Even with these challenges, experiments and on-farm trials are beginning to show that with proper planning, cover crops can be worked into HT crop rotations with positive results.

Key Management Considerations

Planting times. Winter and summer generally provide the best windows to work cover crops into HT rotations in the South. Cool-season cover crops can be sown in late fall, but must be established before temperatures become too cold for germination and day light too short for plant growth. Some studies have shown that inter-seeding cover crops in between actively growing crop rows, such as peppers, can be successful for establishing a good winter cover crop (Perkus et al., 2019). However, timing is important as seeding too early can potentially reduce yields if there is competition between the cash and cover crop. During the heat of summer, air temperature in HTs often reaches over 100°F, which is unsuitable for most cash crops; however, heat tolerant cover crops can be successfully grown. A general planting schedule and strategies for working cover crops into a HT crop rotation are listed in Table 2 on Page 3. For additional information on species, seeding rates, and other strategies for warm-season and cool-season cover crops, please see the Center for Crop Diversification s *Cool-Season Cover Crops for High Tunnels* and *Warm-Season Cover Crops for High Tunnels* Extension publications (coming soon!).

Recommended Heat-Tolerant Covers

Grasses: sorghum-sudangrass, Japanese millet, annual ryegrass

Legumes: sunn hemp, cowpeas

Broadleaf: sunflowers

Table 2. General planting schedule & strategies for working cover crops into a high tunnel crop rotation

Cover Crop Type	Rotation Timing	Suggested Planting Schedule
Cool-Season Cover Crops	Overwintering – Planted in place of winter cash crop	After HT soils cool, up to 4-6 weeks after covers would be planted in the open field.
Warm-Season Cover Crops	Summer – Planted after a spring cash crop and/or before a fall cash crop	Generally one month earlier than in the open field.
	Winter-killed – Planted after a summer cash crop.	At least 6-8 weeks prior to frost in HTs. Generally 4-6 weeks prior to frost in the open field.

Planting methods. Cover crop seeds can be broadcast by hand or planted with a walk-behind seeder and then raked in to lightly bury them and ensure good soil contact (this will ensure better seed germination). Soils do not necessarily need to be tilled prior to seeding cover crops, but having loose soil to cover the seeds and ensure good soil contact is essential. Be careful not to seed cover crops too densely – when converting from field seeding rates to the smaller areas in the HT, the amount of seed needed may be surprisingly small. Overhead watering is best for germinating the cover crop, as drip line must be removed prior to incorporating the cover crop and this can be difficult if the biomass is lush at termination. In addition, drip irrigation can cause uneven cover crop germination with good growth only right around the drip line.

Managing growth. Planning is key to ensure the cover crop does not interfere with cash crop plans. Residue can interfere with establishment of small-seeded crops and make transplanting more difficult. Residue decomposition requires moisture from irrigation and sufficient time. Producers must leave ample time for complete termination and sufficient residue decomposition prior to planting. Because of these concerns and in the confined space of a HT, sometimes "less is more" when it comes to cover crop biomass. Choosing a less vigorous cover crop can be a good strategy if your window for growing a cover crop is short. Also, keep in mind that cover crops mature more quickly with the added warmth of a HT, often reaching maturity in six to eight weeks. Some cover crops may have sufficient growth to provide the desired benefit in just four weeks.

Termination. With the "less is more" concept in mind, it is important to plan termination carefully. As with cover crops in the field, terminate the cover crop before it sets seed to get the most nitrogen from the biomass and to prevent the cover crop from becoming a weed. The most common method for termination is to mow, and then till in the residue; mowing helps the residue break down faster. If your field equipment for mowing cover crops will not fit in your tunnel, you must plan for how you will terminate the crop. String mowers, push mowers, smaller riding mowers and walk-behind tractors can be good options. With these options, the chopped residue can then be tilled in, or raked to serve as mulch for the next crop. One strategy for being ready for an early spring planting of tomatoes or peppers could be to plant a warm-season cover in late fall that will winter kill, such as buckwheat, Japanese millet, or cowpea. This crop will likely grow in the high tunnel into December or January (barring any extreme early freezes) and then freeze before biomass becomes too much. This strategy reduces equipment needs and allows more time for residue decomposition in the late winter/early spring period.

Timing for growth and decomposition. The dry environment of HTs will prevent the biomass from breaking down, so it is essential to water the soil and cover crop residue regularly to ensure that it is decomposed sufficiently before planting your next crop. Plan for two to three weeks for the cover crop residue to decompose. Although grass cover crops can be effective scavengers of nutrients already in the soil, they can tie up nutrients and stunt the next crop if they have not been given enough time and moisture to break down (Fig. 2). Legumes and legume-grass mixes tend to decompose more rapidly than grasses alone, due to the nitrogen contribution from the legume speeding up the decomposition rate.

Figure 2. Stunted growth in tomatoes grown in bed after incomplete breakdown of winter wheat cover (right) compared to crimson clover cover (left).

Selecting the Right Cover Crops for You

Cover crops work best when you think carefully about what benefits you want them to provide. For example, if you want a cover crop to help manage a nematode problem, you need to select a cover crop species and variety that has been shown to reduce nematode populations. Second, you need to determine a time that you can devote HT space to a cover crop and for how long. You should plan on at least six weeks for adequate growth and time for decomposition. If the cover crop you need to address a particular problem cannot be grown during the timeframe you want to use, you will have to look for other cover crop options or rework the crop schedule for the HT to accommodate the cover crop.

See the publications below for information on specific cover crops recommended for high tunnels, ideal planting and seeding rates, termination tips, and more. Note that some practices discussed in Options for Including Cover Crops in High Tunnel Rotations in the Northern United States may not work for conditions in the Southern United States.

Resources

• Cool-Season Cover Crops for High Tunnels and Warm-Season Cover Crops for High Tunnels, Extension publications (coming soon!)

• Perkus, E., A. Pfeiffer, C. Thurston, F. Li, & J. Grossman. 2019. Options for Including Cover Crops in High Tunnel Rotations in the Northern United States. eOrganic. https://eorganic.org/node/25214

• National Resources Conservation Service, High Tunnel System Initiative. https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/programs/?cid=stelprdb1046250

• Southern Cover Crops Council. https://southerncovercrops.org/

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Reviewed by Shawn Wright, UK Horticulture Specialist, and Lewis Jett, West Virginia University Extension Specialist

Photos courtesy of Tim Coolong (Figure 1) and Jenny Moore (Figure 2) **July 2020**

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University of Kentucky College of Agriculture, Food and Environment
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Center for Crop Diversification System Profile
CCD-SP-19

Warm-Season Cover Crops for High Tunnels in the Southeast

Tim Coolong[1], Julia Gaskin[1], Erin Haramoto[2], Krista Jacobsen[2], Jenny Moore[3], Tim Phillips[2], Rachel Rudolph[2], Annette Wszelaki[3]

High tunnels (HTs) can provide for year-round production in our region, but soil quality can suffer with back-to-back planting of cash crops. Adding cover crops into the rotation can provide many benefits, including adding organic matter and nitrogen and suppressing weeds. The timing and cover crop selection, however, can vary from field crop production. In the Southeastern region, there is typically a six- to eight-week window in summer that provides a good opportunity to grow a cover crop before fall cash crop plantings. Based on trials in Kentucky, Tennessee and Georgia, and on other investigations, this publication outlines several warm-season cover crops that may be used in HTs in the Southeast, along with their benefits and challenges. This fact sheet complements an introduction to cover crops in high tunnels (Covers Under Cover: Managing Cover Crops in High Tunnels; CCD-SP-16); cool-season cover crops are reviewed in fact sheet number CCD-SP-18.

Selecting the right warm-season cover crop for you. Determine what you want the cover crop to do for your production system. Some cover crops will add nitrogen to the system, while others may produce a lot of biomass in a short period of time and add organic matter to the soil. Ensuring adequate time in the rotation for both cover crop growth and decomposition is an important consideration that is discussed in greater detail below (see *Termination* section). Summer can be a great time to include a cover crop in a high tunnel rotation, but being mindful of heat and drought tolerance, as well as the quantity of biomass produced is key to summer cover crop success. Finally, consider what crop will follow the cover crop and what equipment you have available for termination and incorporation. For example, if you have a long growing window but will direct seed a small-seeded cash crop and have limited equipment for incorporation, you may want a slow-growing cover crop that will not accumulate much biomass. To aid in decision-making, Table 1 (Page 4) contains a description of the general traits, benefits and challenges of some specific cover crops that we have worked with in HTs. Table 2 (Pages 5 and 6) gives seeding rates and other general information about the cover crop species listed in Table 1, along with other varietal suggestions, but is not an exhaustive list.

Planting and establishment. Warm-season cover crops can be planted as soon as the risk of frost in the high tunnel has passed, generally one month prior to the open field. If the HT temperature is still low and sunlight is limited, establishment may be slower. Planting in the peak heat of the summer, however, may also lead to reduced establishment of some species. Ensuring seeds have good soil contact, and that the seedbed remains moist during germination and early growth, is key to growing a good cover crop stand.

Managing growth. Growing a cover crop during the summer months is a great way to get rapid cover crop growth in a short window of time. Typically, warm-season

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cover crops are tolerant of high soil temperatures, and they will grow most rapidly when the weather is consistently warm and there is ample sunlight. However, this also means that soils dry out more rapidly than in cooler weather so irrigation is critical. In our trials on our research farms and with producers, we have seen some cover crops reach peak biomass in four weeks. With this rapid growth, it is very important to regularly check cover crops to make sure they are not growing too large to be managed by whatever method is going to be used to terminate the cover crop.

Termination timing and methods. Leaving adequate time for cover crop residue decomposition is important to ensure the success of the next cash crop. This is particularly critical if the cover crop produces a lot of biomass, and/or if that biomass has a lot of carbon relative to nitrogen – these factors will lead to slower cover crop decomposition. In general, more mature cover crops take longer to decompose. High carbon cover crops, including grasses, can immobilize nutrients as they decompose. Some legumes, including sunn hemps, can also become woody as they mature and this will also slow the decomposition process and make incorporation more difficult. So, if cover crops are being grown in limited time windows, or if the biomass is very vigorous, it may be necessary to terminate a cover crop prior to peak biomass to allow time for decomposition. To ensure cover crops are effectively terminated, it may be necessary to mow very close to the soil surface, wait at least a day or two for the biomass to dry, and then till in the cover crop residue. The beds should be monitored and tilled again as needed for any regrowth. Irrigation and warmer HT temperatures will accelerate decomposition. As a general rule, allow yourself one to two weeks after cover crops are incorporated before you plant your next cash crop. If smaller-seeded crops are direct seeded, wait longer; most transplants can be planted earlier. Rake remaining cover crop residue out of the beds before planting, or give it more time to decompose.

Considering plant-parasitic nematodes. When choosing a warm-season cover crop for your HT rotation it is important to investigate if plant-parasitic nematodes are a problem in your area. Southern root-knot nematode (*Meloidogyne incognita*; RKN) is a common plant parasite that infects and feeds on plant roots. As a result of the feeding, plant roots form galls, or knots. The feeding reduces a crop's ability to take up nutrients and water, which can decrease subsequent crop yields and even lead to plant death. If RKN infects root crops, this can also affect marketability of the crop. Knowing the host suitability of a particular cover crop is useful because it can help indicate whether the RKN population is likely to increase, decrease or stay the same when in the presence of the cover crop. If a cover crop is a good host for a plant-parasitic nematode, that nematode population is likely to increase during the cover crop's lifecycle, which is not good. Being a poor host indicates that the nematode does not easily infect and reproduce in the presence of that cover crop and the specific nematode population (not all nematodes) will likely decrease. Your local Cooperative Extension Service or plant diagnostic laboratory can help you determine if these plant-parasitic nematodes are present in your soil. If you know you have RKN in your soil, you should avoid planting crops and cover crops that are known hosts for RKN. Keep in mind that different cultivars within a cover crop species can have different levels of host suitability (for example, 'Chinese Red' cowpea is a poor host, but 'Iron Clay' cowpea is a good host). When soil temperatures are 80°F, RKN can complete one lifecycle in approximately 25 days. High tunnel soils will likely be at or around that temperature in the summer months. When environmental conditions, such as temperature, are conducive to RKN reproduction, it is even more important to select a non-host cover crop.

Cover Crop Seed Sources

Albert Lea Seed (Albert Lea, Minnesota)
Website: https://www.alseed.com
Phone: (800) 352-5247

Center Seeds (Sidney, Ohio)
Website: https://centerseeds.com/
Phone: (855) 667-3943

Johnny's Selected Seeds (Winslow, Maine)
Website: www.johnnyseeds.com
Phone: (877) 564-6697

Seven Springs Farm (Check, Virginia)
Website: www.7springsfarm.com
Phone: (800) 540-9181

Petcher Seeds (Fruitdale, Alabama)
Website: www.petcherseeds.com
Phone: (251) 827-6594

Southern Exposure Seed Exchange (Mineral, Virginia)
Website: www.southernexposure.com
Phone: (540) 894-9480

Hancock Seed Company (Dade City, Florida)
Website: www.hancockseed.com
Phone: (800) 552-1027

Cover Crop Resources

Managing Cover Crops Profitabl
(free download from USDA-SARE):
https://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Editio

Southern Cover Crops Council
Website: www.southerncovercrops.org

Midwest Cover Crops Council
Website: www.mccc.msu.edu

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Reviewed by Shawn Wright, UK Horticulture Specialist, and Lewis Jett, West Virginia University Extension Specialist
Photos courtesy of Erin Haramoto, University of Kentucky **June 2021**

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Table 1. A sampling of cover crops varieties tested in high tunnels and their traits.

Cover Crop	Traits						Tolerance			Comments
	N Fixing	N Scavenging	Soil Builder	Weed Suppression	Quick Growth	Host for Southern root-knot nematode*	Heat	Drought	Low Fertility	
Cowpea, Chinese Red	Yes	Fair	Fair	Fair	Good	Yes	Very Good	Very Good	Very Good	More vining habit and earlier to mature than Iron and Clay.
Cowpea, Iron and Clay	Yes	Fair	Good	Fair	Good	No	Very Good	Very Good	Very Good	Blend of a bush and vining varieties. Rapidly maturing; however, vining plants keep growing even as seeds mature, giving later biomass. Heat and drought tolerant once germinated.
Millet, German	No	Good	Fair	Good	Excellent	Unknown	Very Good	Good	Poor	Matures a few weeks later than Japanese millet.
Millet, Japanese	No	Good	Good	Good	Excellent	Yes	Very Good	Good	Poor	Rapidly maturing after initial establishment.
Sesame	No	Unknown	Excellent	Very Good	Fair	No	Excellent	Excellent	Unknown	Tolerates high heat, breaks down quickly.
Sunn Hemp, various cultivars	Yes	Very Good	Very Good	Good	Fair	No	Excellent	Very Good	Very Good	Prone to rodent and rabbit damage, can be difficult to establish. Very drought tolerant and rapid growth.
Teosinte	No	Good	Excellent	Excellent	Unknown	Unknown	Excellent	Very Good	Unknown	Less biomass than a sorghum-sudan crop. Excellent weed suppression.

*See *Considering plant-parasitic nematodes* on Page 2.

Table 2. Seeding rates, potential benefits and challenges for the warm-season cover crop species listed in Table 1. For some species, other varieties are suggested, but the variety recommendations are not meant to be exhaustive.

Cowpea

- Seeding rate: 100-150 lbs/ac (2.25-3.5 lbs/1000 ft^2) broadcast
- Potential benefits:
  - Fixes N
  - Decomposes rapidly
  - Low water use
  - Saline tolerant
  - Quickly shades out weeds
  - Easy to establish (except for Iron & Clay, which is slower than other cowpea)
  - Iron & Clay are poor hosts for Southern root-knot nematode
- Challenges:
  - Chinese Red is host for Southern root-knot nematode
  - Nematode host status is variety dependent; be sure to check this if nematodes are a problem in your HT!
  - Has some hard seededness – not all may germinate soon after planting and will "volunteer" in subsequent seasons

Millet, German

- Seeding rate: 20 lbs/A (0.5 lbs/1000ft^2) broadcast
- Potential benefits:
  - Low water use
  - High biomass
  - Matures a little later than Japanese millet (7-10 days later in the summer)
- Challenges:
  - Host for Northern root-knot nematode
  - Host status for Southern root-knot nematode is unknown

Millet, Japanese

- Seeding rate: 25-30 lbs/ac (0.6-0.7 lbs/1000ft^2) broadcast
- Potential benefits:
  - Low water use; high heat and drought tolerance
  - Rapid growth and maturity
  - High biomass (but less than German)
  - Weed suppression
  - Rapid summer growth (matures in 45 days)
  - Can have vigorous re-growth with mowing
  - Pairs well with cowpea
- Challenges:
  - Also called "million seed plant;" terminate before seed set
  - Host for Southern root-knot nematode (and other species of RKN)

Sesame

- Seeding rate: 6-10 lbs/ac (2.25 – 3.75 ounces/1000 ft^2) broadcast
- Potential benefits:
  - Quick growth once established
  - High biomass
  - Weed suppression
  - Quick decomposition
  - Not a host for Southern root-knot nematode
  - Not a common plant family
- Challenges:
  - Does not tolerate wet soils

Sunn Hemp

- Seeding rate: 20-40 lbs/A (0.5-1 lb/1000 ft^2) broadcast
- Potential benefits:
  - Fixes N
  - Low water use
  - High biomass
  - Deep taproot
  - Poor host for Southern root-knot nematode
- Challenges:
  - Can produce a lot of biomass! Woody stems can result, making termination and incorporation more difficult

Teosinte

- Seeding rate: 25 lbs/A (0.6 lbs/1000 ft^2) broadcast
- Potential benefits:
  - High biomass
  - Weed suppression
- Challenges:
  - Can produce a lot of high C biomass
  - Plant-parasitic nematode host status is unknown

University of Kentucky
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Cooperative Extension Service

Center for Crop Diversification System Profile
CCD-SP-18

Cool-Season Cover Crops for High Tunnels in the Southeast

Tim Coolong[1], Julia Gaskin[1], Erin Haramoto[2], Krista Jacobsen[2], Jenny Moore[3], Tim Phillips[2], Rachel Rudolph[2], Annette Wszelaki[3]

Cool-season cover crops can be grown in high tunnels (HTs) in the fall or winter if you have a window of time between cash crops. Winter cover cropping is a common practice for many growers in the field, but cover crops perform differently in HTs. Additionally, there is often a shorter window for cover crops in HTs because many cash crops can be grown year-round in our region. However, just like in the field, cover crops can provide many benefits within the HT production system. This publication, based on trials in Kentucky, Tennessee and Georgia, outlines the benefits and challenges of several cool-season cover crops that may be used in HTs. This fact sheet complements an introduction to cover crops in HTs (Covers Under Cover: Managing Cover Crops in High Tunnels; CCD-SP-16) and a fact sheet on warm-season cover crops in HTs (CCD-SP-19).

Selecting the right cool-season cover crop. Consider your goals for the cover crop: supplying nitrogen, suppressing weeds, adding organic matter, or reducing compaction. Next, consider how much time you have in your rotation for cover crop growth and decomposition. Cover crops, like cash crops, grow very slowly during the winter with low air and soil temperatures, reduced light intensity, and shorter daylength. Therefore, it is important to select a cover crop that is tolerant of the growing conditions, and that will grow enough to meet your goals. You should also consider the amount of biomass the cover crop will produce and the equipment you have to effectively terminate and incorporate that biomass. To aid in decision-making, Table 1 (Page 4) contains a description of the general traits, benefits and challenges of some specific varieties of cover crops that we have used. Table 2 (Pages 5-8) gives seeding rates and other general information about the cover crop species listed in Table 1, along with other varietal suggestions, but it is not an exhaustive list.

Planting and establishment. Covers Under Cover (CCD SP-16) gives many general tips on establishing cover crops in HT environments. In general, cool-season cover crops should be sown later in HTs than would be typical for cover crops in field settings. Due to higher soil temperatures and evapotranspiration in HTs, establishment can be difficult and plant growth may suffer if cool-season cover crops are sown too early. However, planting too late when temperatures are low may decrease establishment and will likely lead to lower cover crop biomass as well. Additionally, having a way to irrigate your cover crop during establishment is very important.

Managing growth. Unlike in the field, cool-season cover crops may not go dormant in HTs in the winter, but growth will be slowed by cool temperatures and fewer hours of daylight. Irrigation may be needed over the course of cover crop growth, though less regular irrigation will likely be necessary for cool-season cover crops. On cool, overcast days, be careful to not irrigate too much to reduce po-

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Figure 1. Oats in a high tunnel at the University of Kentucky Horticulture Research Farm.

tential for disease. The soil should not stay saturated. If high biomass production is a goal for cool-season cover crops, it may require earlier planting (which will require terminating a late summer/early fall cash crop earlier), or later termination (which will require planting a spring cash crop later). For example, from our experience in Kentucky and Tennessee, a cover crop planted in late October in a high tunnel will not reach peak biomass until late March, with much of the growth occurring during February as temperatures warm and light becomes more abundant. Lower cover crop biomass may be advantageous in some cases – if limited equipment is available for termination, or to avoid potential nitrogen immobilization (see below). It is important to consider your goals for using a cover crop when determining planting and termination dates. Alternatively, biomass may be managed by mowing at desired height before termination to keep grazing/mowing-tolerant cover crops smaller.

For quick, early growth in the fall, select fast-establishing cool-season cover crops that generally do well in the open field in your location. Options include oats (Fig. 1) or other small grains including wheat and crimson clover. If your cash crop rotation includes brassica crops (kale, turnip greens, etc.), then avoid brassica cover crops such as mustards and canola.

Termination and decomposition. Be sure to consider termination timing and method, and allow a few extra weeks for the cover crop to decompose before planting your next cash crop. If your goal is to maximize the amount of nutrients and biomass in the cover crop, cool-season cover crops should be terminated when legumes are flowering, or grasses and small grains are at a "soft dough" stage (soon after a head forms and you can see immature seeds/grains). You can terminate the cover crops early with mowing and incorporation (i.e., without herbicides), but you may get some regrowth. A thick cool-season cover crop can be very lush and require drying time (two to three days) before it can be effectively incorporated into the soil. A second tillage pass about a week after the first is often required. Vetches and other vining cool-season cover crops can be difficult to manage and bind around mowing equipment. As we discuss in the Covers Under Cover: Managing Cover Crops in High Tunnels fact sheet (CCD SP-16), HT cover crop residue management may require a "less is more" strategy; therefore, early termination when there is less biomass can make the cover crop residue easier to manage.

Termination timing must also be balanced with weed management – primarily, the need to avoid adding weed seeds to the soil, but also being aware of weeds as potential hosts of pest insects and diseases. Weed suppression by cover crops can depend on multiple factors, including weed pressure, cover crop type, evenness and thickness of the cover crop stand, air temperature, and moisture. High tunnel trials in Tennessee found winter wheat (Fig. 2) to be very effective at smothering winter annual weeds but less so in Kentucky, where weed pressure was dominated by common chickweed. By irrigating the cover crops, weed growth was also increased and common chickweed produced seeds prior to cover crop termina-

Figure 2. Thick winter wheat cover crop in a HT in Knoxville, TN (left) compared to a more weedy winter wheat cover crop in Lexington, KY (right), both in late winter.

tion. Therefore we inadvertently added weed seeds to the soil. This demonstrates an important point - you should always be aware of weeds growing in the cover crop and, if necessary, terminate the cover crop before these produce seed. If terminated prior to seed production, the cool-season weeds contribute to the total biomass. Chickweed samples were tested for nitrogen content and were 4% nitrogen, which is better than some covers in terms of scavenging ability!

It is important to allow enough time for the cover crops to decompose, or they will immobilize nutrients. Cover crops decompose more slowly if the soil is cool, too dry, or if there is a large amount of carbon relative to the amount of nitrogen in the cover crop. This means decomposition of a cool-season cover crop can take longer than at warmer times of the year. It also means that the soil must be consistently moist (but not saturated) for the cover crop to decompose, so be sure to have a way to irrigate in place to aid decomposition. In general, grasses grown alone will take longer to decompose than when grown in a mixture with legumes or other broadleaves, or legumes grown alone. As a general rule, allow two to three weeks after cover crops are tilled in to the soil prior to planting your next crop. If you can see remaining cover crop residue in the soil when you are preparing the bed for the next crop, this material should be raked out of the bed or given additional time to decompose.

Considering plant-parasitic nematodes. One other factor to consider when chosing a cool-season cover crop for your HT rotation is if pest nematodes are a problem in your area. Southern root-knot nematode (*Meloidogyne incognita*; RKN) is a common plant parasite that infects and feeds on plant roots. As a result of the feeding, plant roots form galls, or knots. The feeding reduces a crop's ability to take up nutrients and water, which can decrease subsequent crop yields and even lead to plant death. If RKN infects root crops, this can also affect marketability of the crop. Knowing the host suitability of a particular cover crop is useful because it can help indicate whether the RKN population is likely to increase, decrease or stay the same when in the presence of the cover crop. If a cover crop is a good host for a plant-parasitic nematode, that nematode population is likely to increase during the cover crop's lifecycle. Being a poor host indicates that the nematode does not easily infect and reproduce in the presence of that cover crop and the specific nematode population (not all nematodes) will likely decrease. Your local Cooperative Extension Service or plant diagnostic laboratory can help you determine if these plant parasitic nematodes are present in your soil. If you know you have RKN in your soil, you should avoid planting crops and cover crops that are known hosts for RKN. Keep in mind that different cultivars within a cover crop species can have different levels of host suitability (for example, 'Chinese Red' cowpea is a poor host, but 'Iron Clay' cowpea is a good host).

Cover Crop Seed Sources

Albert Lea Seed (Albert Lea, Minnesota)
Website: https://www.alseed.com
Phone: (800) 352-5247

Center Seeds (Sidney, Ohio)
Website: https://centerseeds.com/
Phone: (855) 667-3943

Johnny's Selected Seeds (Winslow, Maine)
Website: www.johnnyseeds.com
Phone: (877) 564-6697

Seven Springs Farm (Check, Virginia)
Website: www.7springsfarm.com
Phone: (800) 540-9181

Petcher Seeds (Fruitdale, Alabama)
Website: www.petcherseeds.com
Phone: (251) 827-6594

Southern Exposure Seed Exchange (Mineral, Virginia)
Website: www.southernexposure.com
Phone: (540) 894-9480

Hancock Seed Company (Dade City, Florida)
Website: www.hancockseed.com
Phone: (800) 552-1027

Cover Crop Resources

Managing Cover Crops Profitabl
(free download from USDA-SARE):
https://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Editio

Southern Cover Crops Council
Website: www.southerncovercrops.org

Midwest Cover Crops Council
Website: https://mccc.msu.edu/

Table 1. A sampling of cover crops varieties tested in high tunnels in Kentucky, Tennessee and Georgia, and their traits.

Cover Crop	Traits						Tolerance			Comments
	N Fixing	N Scavenging	Soil Builder	Weed Suppression[a]	Host for Southern root-knot nematode	Quick Growth	Cold	Drought	Low Fertility	
Clover, Crimson, Dixie	Yes	Good	Good	Very Good	Yes	Good	Fair	Fair	Good	Not tolerant of poorly drained or highly alkaline soils.
Clover, Common Mammoth	Yes	Good	Good	Very Good	Unknown[b]	Fair	Very Good	Fair	Fair	Dependable.
Hairy Vetch, variety not stated	Yes	Fair	Fair	Good	Yes	Fair	Good	Good	Fair	Slow early growth. Excellent for N source. Excessive biomass can be a challenge. Reseeds and can become a weed
Mustard, Pacific Gold	No	Excellent	Very Good	Very Good	Yes	Very Good	Good	Very Good	Fair	Not heat tolerant. Rapidly maturing. Do not use with other brassicas in rotation
Oat, Bob	No	Very Good	Very Good	Excellent	No	Excellent	Poor	Fair	Good	Easier to terminate and earlier to mature than rye.
Oilseed Radish, Sodbuster	No	Excellent	Very Good	Excellent	No	Very Good	Poor-Fair	Fair	Fair	Breaks up soil compaction. Scavenges N from deeper soil level. Do not use with other brassicas in rotation
Rye, Cereal, Wren's Abruzzi	No	Excellent	Excellent	Excellent	No	Excellent	Very Good	Very Good	Excellent	Southern-adapted rye cultivar.
Annual Ryegrass, Marshall	No	Good	Good	Good	No	Good	Good	Fair	Good	Effective N scavenger. Tolerant of cool soils for germination.
Triticale, Triticale 102	No	Good	Very Good	Good	Unknown[c]	Good	Good	Good	Good	High saline tolerance. Later fall planting tolerance. Fibrous root system.
Winter Wheat	No	Very Good	Very Good	Very Good	Variable[d]	Very Good	Good	Good	Good	Easier to terminate than rye. Not likely to become weed problem.

[a]Weed suppression can vary depending on the cover crop stand and biomass produced. [b]Host status is unknown for this particular variety; however, most clover varieties are hosts for RKN.
[c]Host status is unknown for this particular variety; however, other triticale varieties are hosts for RKN. [d]Host status for winter wheat depends on the variety; some are non-hosts and some are hosts for RKN.

Table 2. Seeding rates, potential benefits and challenges for selected cool-season cover crop species listed in Table 1. For some species, other varieties are suggested, but the variety recommendations are not meant to be exhaustive.

Annual Ryegrass
• Seeding rate: 25 lbs/acre; 9-10 oz/1000 sq. ft.
• Potential benefits:
  • Seed is readily available
  • Generally winter hardy
  • Good weed suppression and biomass production if stand is well-established
• Potential challenges:
  • Germination and establishment can be difficult at high soil temperatures in late summer
• Other varieties: Attain, Bruiser, Gulf, Rival	

Clover, Crimson
• Seeding rate: 15-20lbs/acre; 5-7 oz/1000 sq. ft.
  • If seed is pre-inoculated, check the label for information on the mass of the seed coating and adjust seeding rate accordingly. For example, if label indicates 70% seed and 30% coating by weight, increase the seeding rate by approx. 40% (the coating weight is approx. 40% of the seed weight).
  • If seed is not pre-inoculated, mix with inoculum for best N fixation
• Potential benefits:
  • Generally winter hardy
  • Fixes N
  • Decomposes rapidly
  • Easy to establish
• Potential challenges:
  • Can be vigorous and re-grow if not effectively terminated
  • Host for Southern root-knot nematode
• Varieties: AU Robin and AU Sunrise (early maturing), Kentucky Pride	

Clover, Red
• Seeding rate: 10-12 lb/acre; 3.5-4.5 oz/1000 sq. ft. See inoculation notes for crimson clover.
• Potential benefits:
  • Generally winter hardy
  • Fixes N
  • Decomposes rapidly
  • Easy to establish
• Potential challenges:
  • May be slower to establish than crimson clover	

Hairy Vetch (*Vicia villosa*)
• Seeding rate: 15 lbs/acre; 5.5 oz/1000 sq. ft. See inoculation notes for crimson clover.
• Potential benefits:
  • Very winter hardy, can be seeded after many other cool-season covers
  • Fixes N
  • Decomposes rapidly
  • Easy to establish
  • Good companion to cool-season grasses due to vining growth habit
• Potential challenges:
  • May be difficult to mow due to vining growth habit
  • Not competitive with winter annual weeds
  • Host for Southern root-knot nematode
  • May have volunteer vetch plants in subsequent years due to hard seed that does not germinate in the year it is planted.
• Varieties: Purple Bounty, Purple Prosperity, AU Merit	

Mustards
• Seeding rate: 10 lbs/acre; 3.5 oz/1000 sq. ft.
• Potential benefits:
  • Quick growth
  • Easy to establish
  • May be effective biofumigant for some plant-parasitic nematodes
  • Quickly shades out broadleaf weeds
• Potential challenges:
  • May be a host to diseases and insects of Brassica crops, so avoid if you grow brassicas as a cash crop
  • Termination and incorporation **must** be managed correctly to be effective biofumigant
  • May be a host for Southern root-knot nematode. Host status differs by variety.
• Varieties: Idagold, white mustard, yellow mustard	

Oats, spring
• Seeding rate: 100 lbs/acre; 2.3 lb/1000 sq. ft.
• Potential benefits:
  • Easy to establish
  • Quickly shades out weeds
  • Earlier maturing than other cool-season grasses
  • Less biomass than other cool-season grasses, such as cereal rye
• Potential challenges:
  • Don't use bin run seed. Although cheaper can contain weed seeds.
• Varieties:
  • Coker 227, Cosaque
  • Forage varieties such as Horizon 720 and Legend 567 produce more leaves
  • Graham (shorter variety)
  • Shelby, Saber	

Rye, Cereal
• Seeding rate: 80 lbs/acre; 1.8 lb/1000 sq. ft.
• Potential benefits:
  • Easy to establish
  • Quickly shades out weeds
  • Very cold-tolerant
  • May be seeded later than other cool-season cover crops
  • Poor host for Southern root-knot nematode
• Potential challenges:
  • Later maturing than other cool-season grasses
  • May produce more biomass than can be handled with small-scale equipment
  • Don't use bin run seed. Although cheaper can contain weed seeds.
• Varieties:
  • Aroostook, Elbon, Florida 401 (earlier maturing), Wheeler, Wintergrazer	

Radish, Oilseed
• Seeding rate: 8 lbs/acre; 3 oz/1000 sq. ft.
• Potential benefits:
  • Taproots reduce soil compaction
  • Relatively easy to establish
• Potential challenges:
  • Must be established early to achieve large taproot growth, which can be difficult in warm tunnel soils
  • May be a host to diseases and insects of Brassica crops
  • Must factor in to your rotation if you grow brassicas as a cash crop
• Varieties: Ecotill, Tapper	

Triticale
• Seeding rate: 80 lbs/acre; 1.8 lb/1000 sq. ft.
• Potential benefits:
  • Less biomass than rye, but with good winter hardiness
  • Easy to establish
  • Effective weed competitor
• Potential challenges:
  • Can tie up nitrogen if sufficient time is not given for biomass breakdown
• Varieties: NF 201, Trical 342 (forage varieties)	

Winter Wheat
• Seeding rate: 120 lbs/acre; 2.75 lb/1000 sq. ft.
• Potential benefits:
  • Easy to establish
  • Effective weed competitor
  • Good companion with clovers, as matures around same time
• Potential challenges:
  • Don't use bin run seed. Although cheaper can contain weed seeds.	

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Reviewed by Shawn Wright, UK Horticulture Specialist, and Lewis Jett, West Virginia University Extension Specialist

Photos courtesy of Erin Haramoto, University of Kentucky (Figure 1 and Figure 2, right, and annual ryegrass, mustards, oats and radish, Table 2); Jenny Moore, University of Tennessee (Figure 2, left, and winter wheat, Table 2), Julia Gaskin, University of Georgia (crimson clover, triticale and cereal rye, Table 2); Kristi Durbin, University of Kentucky (hairy vetch, Table 2); and Steve Diver, University of Kentucky (red clover, Table 2). **June 2021**

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Vegetable Crops Hotline
A newsletter for commercial vegetable growers prepared by the Purdue University Cooperative Extension Service

Basic Aspects of High Tunnel Soil Fertility Management

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BY: PETRUS LANGENHOVEN

Basic Aspects of High Tunnel Soil Fertility Management – *(Petrus Langenhoven, plangenh@purdue.edu, 765-496-7955)* – Spring has arrived! Every high tunnel grower is now thinking of planting summer vegetable crops in high tunnels or has already planted. Whichever scenario applies to you, I hope that you have submitted soil samples or are in the process of submitting samples to your closest laboratory. Have you analyzed your irrigation water? It will be a good idea to send a water sample along too. There is a lot of important information locked up in your water and soil test results. The results will help you to plan and manage your high tunnel fertility program. Remember, growing in a high tunnel is like growing crops in an irrigated desert. Natural rainfall is unavailable inside your high tunnel and therefore all your plants water needs are satisfied through an irrigation system. Fertilizer needs could be addressed by adding water-soluble fertilizer to irrigation water (fertigating at times throughout the growing season), or by adding compost and other soil amendments prior to planting and during the growing season. High tunnels have some unique problems, which include temperature extremes, possible nutrient deficiencies due to faster crop growth under warmer conditions, salt accumulation in the soil, and faster release of nutrients from organic materials. In anticipation of these issues, growers can plan to manage soil fertility and moisture issues timely. In this article we will be focusing on water quality and the interpretation of your soil test report.

Importance of Water Quality Testing – The effect of using of high alkalinity irrigation water in greenhouse bench crop production is well known. Over time, the water can cause a rise in soil or media pH, resulting in deficiencies of zinc, manganese and iron in specific crops. High tunnel growers experience this problem too. Total alkalinity and pH of your irrigation water should be in the range of 0 to 100 ppm $CaCO_3$ and 5.5 to 6.5, respectively. Ideally, it should be about 80 ppm $CaCO_3$ with a pH of 5.8. An additional negative effect of alkalinity levels higher than 150 ppm $CaCO_3$ is an increase in the incidence of clogged drippers. Remember, water pH and alkalinity are not strictly related. Therefore, it is important to test for both. There are two options to deal with high alkalinity and pH. Acidification and a reduction in alkalinity of the irrigation water could be achieved with the addition of an acid (i.e. citric, sulfuric, phosphoric or nitric). Rates could be calculated with this very handy **ALKCALC (https://extension.unh.edu/Agric/AGGHFL/alk_calc.cfm)** resource. Amending your water alkalinity and pH while you irrigate is perhaps the fastest and most cost-effective method to manage soil pH. If you are interested to acidify your soil slowly with an organic amendment, apply elemental sulfur at 15 lb/1000 sq. ft. of bed area for each 0.5 pH unit drop needed (Sideman, 2018). Also make sure that iron, manganese and sulfate is within acceptable ranges. Iron levels higher than 5 ppm could be toxic to the plant and could result in iron precipitates forming at the emitter, plugging your irrigation system. Similarly, manganese levels higher than 1.5 ppm and sulfate levels higher than 240 ppm could cause emitter blockage. It is also important to keep track of the sodium and chloride levels in the water. High levels (>50 ppm Na and >70 ppm Cl) can lead to an increase in soil salinity, especially in the top 2-4 inches, and therefore has to be managed carefully. Particularly in view of the fact that the high tunnel cover prevents natural rainfall from washing or leaching excess soluble salts from the soil and that the elevated soil temperatures inside the tunnel increases soil microorganism activity, releasing nutrients from organic materials such as manures and composts faster into the root zone.

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Understanding your Soil Test Report – The optimum **pH** varies by crop but it is generally accepted that the ideal pH range for organic and mineral soils are 5.3 to 5.8 and 6.0 to 7.0, respectively. In mineral soils nitrogen, phosphorus, potassium, calcium, magnesium, boron and molybdenum are most available when the pH is between 6.0 and 7.0. With a soil pH below 6.5, zinc, manganese, iron and copper tend to be most available. It is therefore desirable to maintain mineral soil pH between 6.0 and 6.5. The available aluminum increases as the mineral soil pH decrease, especially below 5.5. The increasing aluminum concentration can further contribute to soil acidification and aluminum toxicity, which inhibits root growth. The target pH range for organic soils are between 5.3 to 5.8. The lower pH range is acceptable because aluminum levels are very low in organic soils (Warncke et al., 2004). The capacity of a soil to hold exchangeable cations is measured and reported as the **cation exchange capacity** (CEC) of the soil. This value is a good indicator of soil fertility. A good soil has a CEC between 5 and 35 meq/100g soil. Generally sandy soils have a low CEC and soils with a high CEC is more likely to have a high clay or organic matter content. Two tests are performed to determine the **phosphorus** levels, P1 (weak Bray) and P2 (strong Bray). The P1 test is an indication of the phosphorus that is readily available to plants (20 to 50 ppm is adequate) and the P2 test confirms the level of phosphorus that is available and part of the active reserve in the soil (40 to 60 ppm is a desirable level). **Potassium** should be in the range of 150 to 300 ppm, **calcium** 1000 to 2500 ppm, and **magnesium** >50 ppm. **Soluble salts** results are presented as the electrical conductivity (EC) of the soil and is measured in mmhos/cm. An EC <1.0 (<640 ppm salt) is considered good and and EC >2.5 (>1600 ppm salt) is unsuitable for crops. **Percent base (cation) saturation** gives you an indication of what proportion of the CEC is occupied by cations such as Ca^{2+}, Mg^{2+} and K^{+}. Optimum ranges for Ca^{2+}, Mg^{2+} and K^{+} are 40-80%, 10-40%, and 1-5%, respectively. **Micronutrient** ranges for vegetable crops are between 1 to 3 ppm Zn, 1 to 5 ppm Mn, 11 to 16 ppm Fe, 0.5 to 1.5 ppm Cu, 0.7 to 1.0 ppm B, and 0.11 to 0.20 ppm Mo.

Considerations for the Plan – Now you are able to initiate the development of a soil fertility management strategy. **Nitrogen** is an important element to promote vegetative growth. Under warm and high light intensity conditions, over fertilization of nitrogen can lead to excessive growth and deficiencies, especially in fruiting vegetable crops. The nitrogen form applied is also an important consideration. Applying most nitrogen as ammoniacal or urea will result in a soil pH decrease in the root zone. The conversion of these nitrogen forms to nitrate nitrogen is temperature dependent, converting at a faster rate when the soil temperatures are higher. Excess ammonium nitrogen can lead to deficiencies, especially calcium, magnesium and potassium. It is a smaller molecule and are therefore more readily taken up by plants. On the other hand, the uptake of nitrate nitrogen can lead to a slight increase in pH in the root zone. **Phosphorus** is most available to plants at a pH between 6.2 and 7.2. It is therefore important to keep the soil pH in check for maximum availability of phosphorous. Apart from soil amendments, you can adjust your irrigation water pH and nitrogen form to help manage soil pH in the root zone. **Potassium** is an essential element for plant growth and the production of a high quality crop. Higher soil moisture conditions means that more potassium is available in the soil solution and therefore enhances the availability for uptake by plant roots. However, be careful. Excessive soil moisture reduce root respiration, limits root activity and therefore decrease the uptake of potassium. The uptake of both potassium and phosphorus increase with an increase in soil temperature. The optimum soil temperature for uptake is 60 to 80°F.

Remember that recommendations are usually given as pounds per acre of P_2O_5 and K_2O, because fertilizer grades are expressed as percent N-P_2O_5-K_2O. To convert from P to P_2O_5 multiply the P value by a factor of 2.3. To convert from P_2O_5 to P multiply by a factor of 0.43478. Similarly, to convert from K to K_2O multiply the K value by a factor of 1.2. To convert from K_2O to K multiply by a factor of 0.83333. If you would like to know how much of P or K is available in one acre one foot deep, multiply the ppm value in the soil test report by a factor of 3.6.

Use guides such as the ***Midwest Vegetable Production Guide for Commercial Growers (https://ag.purdue.edu/btny/midwest-vegetable-guide/Pages/default.aspx)***, the ***Indiana High Tunnel Handbook (https://www.extension.purdue.edu/extmedia/HO/HO-296.pdf)***, the ***Nutrient recommendation for Vegetable Crops in Michigan***

(http://msue.anr.msu.edu/resources/nutrient_recommendations_for_vegetable_crops_in_michigan_e2934), and the ***Nutrient Management for Commercial Fruit & Vegetable Crops in Minnesota (https://conservancy.umn.edu/handle/11299/51272)*** to help you plan and manage your fertility program.

Resources:

Sideman, B. 2018. High Tunnel Soil Management Update. UMass Extension. Vegetable Notes, Vol. 30 No. 2. **https://ag.umass.edu/sites/ag.umass.edu/files/newsletters/february_15_2018_vegetable_notes.pdf (https://ag.umass.edu/sites/ag.umass.edu/files/newsletters/february_15_2018_vegetable_notes.pdf)**

Warncke, D., J. Dahl and B. Zandstra. 2004. Nutrient recommendation for Vegetable Crops in Michigan. Michigan State University, Extension Bulletin E2934. **http://msue.anr.msu.edu/resources/nutrient_recommendations_for_vegetable_crops_in_michigan_e2934 (http://msue.anr.msu.edu/resources/nutrient_recommendations_for_vegetable_crops_in_michigan_e2934)**

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Why test my irrigation water?

Dewayne Ingram, Professor
Horticulture Department, University of Kentucky

Water quality can have a huge impact on plant growth, especially in soilless plant production systems. Such production systems are extremely diverse, but are most commonly characterized as container production, raised bed production or hydroponics. Soilless systems require intensive management of water and nutrients for optimal plant growth and production. Irrigation water quality impacts nutrient levels and availability as well as other chemical characteristics of the soilless growth substrate. That is why it is critical to characterize the irrigation water source before initiating crops and possibly even during the production of a crop, depending upon the cropping cycle and expected fluctuations in water source.

Water quality factors include physical, chemical and biological properties. Physical properties include suspended solids such as soil particles. The presence of solids in the irrigation water can easily clog low-volume irrigation emitters and even more robust sprinkler heads. Filtering a water sample using filter paper or finely woven cloth can determine if suspended particles are present.

Biological properties of interest include the presence of iron fixing bacteria, plant pathogens or algae. Iron fixing bacteria can react to clog irrigation emitters and is usually associated with excessive iron levels in the water. Plant pathogens, such as water molds, can become an issue in irrigation water, especially if the irrigation water is recycled. Recycled irrigation water can be in a closed system such as hydroponics or more open systems such as holding ponds positioned to capture irrigation runoff water plus rainfall. Algae are most common in slow moving streams or ponds. Biological properties are not included in routine water tests as they are relatively expensive but the expense may be warranted for evaluation of a new water source or to assist in diagnosing the cause of crop plant abnormalities. Sending samples to a specialized, commercial water testing laboratory would be necessary for such analyses not included in a routine water test such as the one available at UK.

Chemical properties of irrigation water are the properties most often tested as they can cause immediate production issues and the information gained from the test can be used immediately in crop management strategies. Only chemical properties are included in the UK Water Test analysis. Chemical properties routinely measured include pH, alkalinity (pH buffering capacity), electrical conductivity (soluble salts), plant macronutrients such as nitrogen, phosphorus, potassium, calcium, magnesium and sulfur and micronutrients such as zinc, copper, iron, manganese and boron.

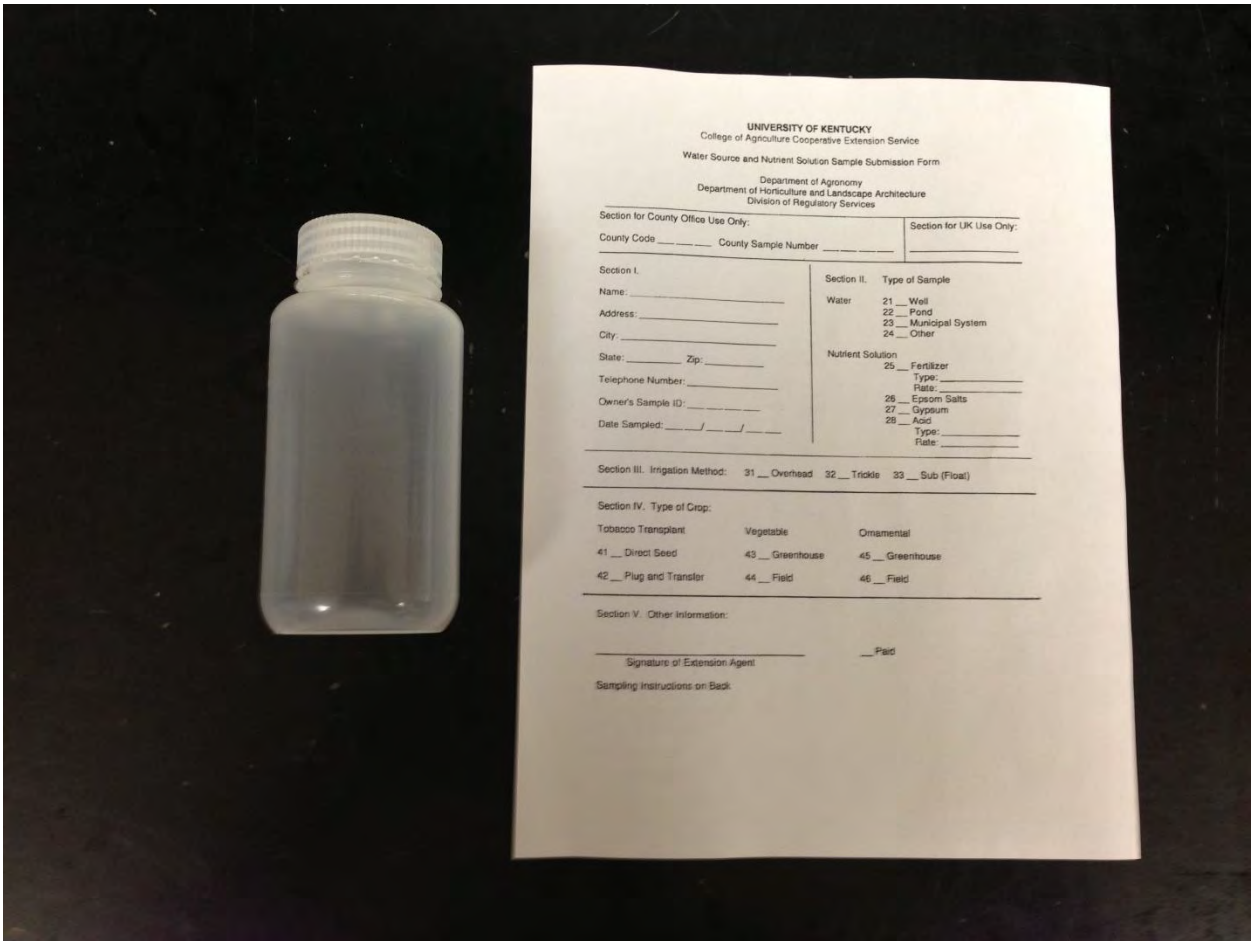
Water testing services are available through the Kentucky Cooperative Extension Service as well as private laboratories. In general the state services are less expensive but may be limited in the number of factors tested. Kentucky growers can submit water samples through the local County Extension Office for analysis by the UK Soil Laboratory in the College of Agriculture, Food and the Environment for a modest fee. The decision of which service to use will depend on the production system and water source. A standard test that measures the most critical water

quality factors is acceptable for most plants including bedding plants, potted flowering crops, hanging baskets, trees and shrubs. More rigorous testing is advisable for hydroponic systems and young plant (plug, liner, or transplant) production. Water tests can also be used to confirm the content of nutrient solutions for fertigation or hydroponics. Pesticide build-up can be an issue in production systems capturing runoff from large blocks of plants. Testing for specific pesticides requires sending samples to specialized, commercial laboratories with the necessary equipment and protocols. Water testing should also be repeated on a regular basis as the quality of water from the same source will vary over time. For example, in times of drought the mineral concentration of water from many sources will increase as some of the water evaporates, leaving the minerals behind in a small volume of water.

Regardless of the service that will be used, the sample collection protocols are generally the same. For samples to be submitted to UK, obtain a sample form and bottle (250 ml plastic) from your County Extension Office. The sample should be collected at the source to prevent contamination from residues in the irrigation system which could skew the test readings rendering the test meaningless. Leave a ½-inch air space at the top of the sample bottle. Replace the bottle cap tightly, mark the sample with the owner identification and return the sample and completed submission form to the County Extension Office. If samples must be held, store them in a refrigerator, but do not freeze them. The more information provided on the submission form about the crops to be grown, any past or current undesirable crop symptoms, etc. will result in more targeted comments and recommendations in the report. A report from the UK Soil Laboratory will be sent electronically to the County Extension Office that sent the water sample to the laboratory. The report will contain the results of the analyses and information from the submission form. The County Extension Agent will provide the report and comments, with assistance from an Extension Specialist as appropriate, to the grower submitting the sample.

Regardless of where you send a water sample for analysis, sampling your irrigation water on a routine schedule is recommended. If you have questions about sampling or analysis options, contact your County Extension Agent or email me at dingram@uky.edu.

Sample bottle and water sample submission form available at your County Extension Office.



UNIVERSITY OF KENTUCKY
College of Agriculture Cooperative Extension Service

Water Source and Nutrient Solution Sample Submission Form

Department of Agronomy
Department of Horticulture and Landscape Architecture
Division of Regulatory Services

Section for County Office Use Only:

County Code ___ ___ County Sample Number ___ ___ ___

Section for UK Use Only:

Section I.

Name: _____

Address: _____

City: _____

State: _____ Zip: _____

Telephone Number: _____

Owner's Sample ID: _____

Date Sampled: ___/___/___

Section II. Type of Sample

Water
21 __ Well
22 __ Pond
23 __ Municipal System
24 __ Other

Nutrient Solution
25 __ Fertilizer
Type: _____
Rate: _____
26 __ Epsom Salts
27 __ Gypsum
28 __ Acid
Type: _____
Rate: _____

Section III. Irrigation Method: 31 __ Overhead 32 __ Trickle 33 __ Sub (Float)

Section IV. Type of Crop:

Tobacco Transplant	Vegetable	Ornamental
41 __ Direct Seed	43 __ Greenhouse	45 __ Greenhouse
42 __ Plug and Transfer	44 __ Field	46 __ Field

Section V. Other Information:

_____ __ Paid
Signature of Extension Agent

Sampling Instructions on Back

Understanding and Managing Irrigation Water Alkalinity

Dewayne Ingram, Professor
Horticulture Department, University of Kentucky

Alkalinity is the measure of the water's ability to neutralize acids including those found in fertilizers and growing substrates. Water that is high in alkalinity will neutralize this acid causing the pH of substrates to rise over time or in some cases very quickly. Alkalinity is composed of dissolved calcium, magnesium, or sodium bicarbonates and calcium or magnesium carbonates. These dissolved carbonate and bicarbonate ions neutralize hydrogen ions which increases the pH of the substrate solution. Most laboratories report alkalinity in ppm (parts per million) or meq/L (milliequivalents of calcium carbonate per liter of water). The UK Soil Testing Lab expresses alkalinity in ppm. The recommended upper limit for alkalinity in irrigation water varies depending on the buffering capacity and volume of the substrate, the cropping cycle and the pH sensitivity of the crop. The larger the substrate volume the more buffering capacity is present so the pH will change much more gradually in large containers than small containers or individual cells in a plug tray.

Plug production is very sensitive to high alkalinity as the very small volume of substrate in the plug has very little buffering capacity, allowing the pH to change rapidly. The same is true in hydroponic systems as the substrate is usually inert, offering almost no buffering capacity. In these systems, problems can occur with an alkalinity as low as 50 to 75 ppm. For production of plants in 4-inch or larger containers that are not particularly pH sensitive, an alkalinity value of up to 150 ppm is manageable. However, an alkalinity of 150 to 300 causes increasing concern, especially if the water pH is greater than 7.5. You can expect the pH of the growing substrate to increase throughout the production cycle if no management strategy is employed. An alkalinity of greater than 300 ppm will cause significant problems if the water pH is greater than 7.5. The substrate pH will rise rapidly throughout the production of the crop and cause many nutrient problems. Ideally, water with such a high alkalinity should not be used for irrigation of container-grown plants. Acid injection may be the only remedy if this water source must be used for irrigation.

Management of Alkalinity

Fertilizer selection is one method to manage pH in soilless production systems when using irrigation water with moderate alkalinity. Every fertilizer is labeled with a potential acidity or basicity value in CCE (calcium carbonate equivalents; lbs/ton). A fertilizer formulation with a high potential acidity can balance the effects of moderately high alkalinity, keeping the substrate pH within an acceptable range. This is especially true in systems where soluble fertilizers are added frequently during irrigation. If this method is used, regular sampling of substrate pH is imperative. Common nursery and greenhouse fertilizers have been carefully formulated and their expected impact on pH is known and documented.

In simple terms, “Potential Acidity” or “Potential Basicity” as listed on the fertilizer package refers to the effect that this fertilizer product has on substrate pH. The higher the number for

"Potential Acidity," the more acidity the fertilizer provides. "Potential Basicity" works the same way. For example, Peters Peat-Lite Special has a moderate acidity potential but their 21-7-7 Acid Special has more than three times the acidification potential.

Acid Injection would likely be necessary if alkalinity is excessively high (300 ppm or more) to make the water suitable for irrigation in soilless production systems. There are several types of acid that are used to neutralize excess alkalinity in irrigation water. No matter which type is used, safe handling of concentrated acids is a serious concern. When mixing any acid, proper safety gear must be worn including safety glasses, face shield, and acid resistant apron, gloves and boots. Also all employees that will be working around the system should be aware of the nature of these materials and what precautions are warranted. When acid injection is necessary it is advisable to invest in an alkalinity test kit to allow monitoring alkalinity on a regular basis to ensure the system is running properly.

The acid must always be added to the water. Never add water to concentrated acid as an energetic reaction will occur that may cause the acid to splash. When mixing an acid solution, measure carefully to ensure accuracy and use acid resistant containers and tools. Always stir the solution after the acid is added as acids are heavier than water and will sink to the bottom of the tank leading to inconsistent injection.

The most commonly used acids are phosphoric, nitric, sulfuric, and citric. The choice of which acid to use depends upon the amount of acidification needed, as well as the relative cost and safety of the material. For moderate alkalinity levels, many growers opt for phosphoric acid as it adds phosphorus to the final fertilizer solution, and is safer and inexpensive than most other acids. For extremely high alkalinity, sulfuric (or battery) acid may be used as it has a higher neutralizing ability but is more hazardous to handle. Citric acid is relatively weaker and more expensive but the safest to handle and may be approved for use in some organic production systems.

Once the choice of acid has been made, the next steps are selecting the right injector and calculating the amount of acid needed in the stock solution. Read the specifications before purchasing an injector for use with acid. The manufacturer will state the maximum concentration of acid that the device can withstand.

There are many factors contributing to the actual alkalinity change that will occur so conducting a test or calibration run of the acid injection system is a must. For more information on calibrating acid injection, please refer to a University of Florida publication on the subject at http://edis.ifas.ufl.edu/ss165.

In summary, it is important to know the characteristics of your irrigation water, especially the alkalinity. Water with above optimum alkalinity water can be used for crop production. Fertilizer choice and acid injection are two tools / protocols available to managers. However, management must be based on test results and the substrate pH must be routinely monitored.

University of Kentucky
College of Agriculture, Food and Environment
Cooperative Extension Service

An IPM Scouting Guide for Common Problems of

High Tunnel and Greenhouse Vegetable Crops in Kentucky

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An IPM Scouting Guide for Common Problems of High Tunnel and Greenhouse Vegetable Crops in Kentucky

This manual is the result of efforts of the University of Kentucky Vegetable IPM team. Funding for this publication is from the University of Kentucky Pest Management Program.

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Sponsored by Kentucky IPM

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Trade names are used to simplify information in this publication. No endorsement is intended nor is criticism implied of similar products that are not named. This guide is for reference only; the most recent product label is the final authority concerning application rates, precautions, harvest intervals, and other relevant information. Contact your county agent if you need assistance.

Long before the term "sustainable" became a household word, farmers were implementing sustainable practices in the form of Integrated Pest Management (IPM) strategies. IPM uses a combination of biological, cultural, physical, and chemical methods to reduce and/or manage pest populations. These strategies are used to minimize environmental risks, economic costs, and health hazards. Pests are managed (although rarely eliminated) to reduce their negative impact on the crop.

Scouting and monitoring diseases, insects, weeds, and abiotic disorders in order to identify potential problems before they result in serious losses is essential to the IPM approach. The key to effective monitoring is accurate identification. The pictures included in this guide represent the more common abiotic and biotic problems that occur on vegetable crops grown in high tunnel and greenhouse structures in Kentucky.

This manual is not all-inclusive, and growers may encounter problems not included here. Please contact a local Cooperative Extension Service office for assistance.

Additional Resources

Additional vegetable crop information on identification, production, fertility, and pest management that could be related to protected agriculture can be found in the following publications; University of Kentucky publications are available at county Extension offices and online.

General Production Guides

Home Vegetable Gardening in Kentucky (ID-128)
http://www.ca.uky.edu/agc/pubs/id/id128/id128.pdf

Vegetable Production Guide for Commercial Growers (ID-36)
http://www.ca.uky.edu/agc/pubs/id/id36/id36.htm

Other Vegetable IPM Scouting Guides

IPM Scouting Guide of Natural Enemies of Vegetable Pests in Kentucky (ENT-67)
http://www2.ca.uky.edu/agc/pubs/ent/ent67/ent67.pdf

IPM Scouting Guide for Common Problems of Cucurbit Crops in Kentucky (ID-91)
http://www.ca.uky.edu/agc/pubs/id/id91/id91.pdf

IPM Scouting Guide for Common Pests of Solanaceous Crops in Kentucky (ID-172)
http://www.ca.uky.edu/agc/pubs/id/id172/id172.pdf

IPM Scouting Guide for Common Problems of Sweet Corn in Kentucky (ID-184)
http://www2.ca.uky.edu/agc/pubs/id/id184/id184.pdf

IPM Scouting Guide for Common Problems of Cole Crops in Kentucky (ID-216)
http://www.ca.uky.edu/agc/pubs/ID/ID216/ID216.pdf

IPM Scouting Guide for Common Problems of Legume Vegetables in Kentucky (ID-227)
http://www2.ca.uky.edu/agc/pubs/ID/ID227/ID227.pdf

Cover: Tomato plant displaying herbicide injury. (Ric Bessin, University of Kentucky)

Physiological Disorders

Blossom end rot on ripening tomato fruit.

1. Blossom end rot appears as soft spots on the blossom end of many vegetable crops, particularly tomatoes, peppers, and squash. The soft spots turn dark brown over time and the fruit is unmarketable. The soft spots can make the fruit more vulnerable to bacteria or fungal pathogens. Blossom end rot is caused by a calcium deficiency in the fruit. This deficiency can be a result of low calcium in the soil, but is most often due to uneven irrigation, especially during high temperatures. Drought stress causes the plants to be unable to take-up and transport calcium. Excessive nitrogen fertilization can also lead to blossom end rot.
Management—Conduct annual soil testing to ensure that soil has the proper calcium levels. Avoid over-fertilization of plants as excessive nitrogen causes more vegetative growth which hinders calcium transport to the fruit. Keep soil moisture consistent, neither too dry or too wet. Ventilate and keep the tunnel as cool as possible during times of high air temperatures. Select cultivars less susceptible to blossom end rot.

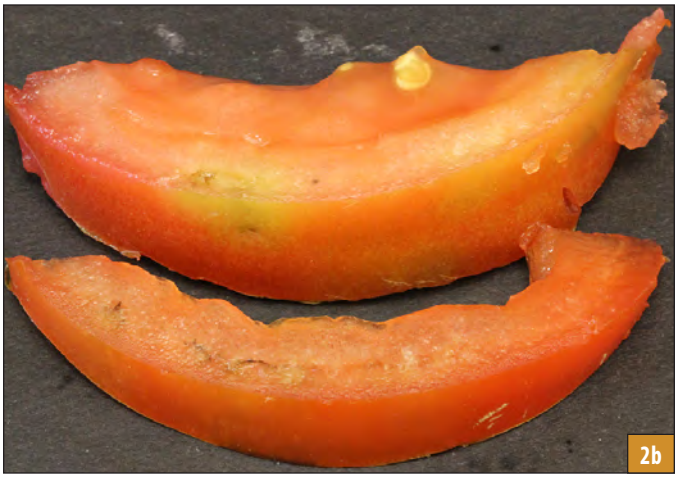
2. Blotchy ripening results in irregularly ripened tomato fruit with green to gray areas on the skin. When fruit is cut, dark necrotic tissue is present internally. Affected fruit are generally not marketable. This condition is associated with short days, cool temperatures, and excessive nitrogen.
Management—Provide adequate potassium fertility to help reduce incidence. Obtain soil and/or tissue nutrient tests; adjust fertility accordingly. As much as possible, modify structure environments to provide optimum growing conditions for crops.

3. Chimera appears as variations in leaf color and is generally manifested as varying shades of yellow and green. These symptoms result from a naturally occurring genetic mutation, which only appears occasionally and randomly. For example, a chimera may be observed on one in 2,500 cucumber plants in a greenhouse. It is generally not considered a problem in vegetable crops.
Management—No action is necessary.

Chimera on English cucumber.

4. Cracking and **fluid leaking** can occur in high tunnels when cucumbers are exposed to cold temperatures in late fall during fruit development. Cool temperatures reduce the elasticity of fruit skin, making it more prone to cracking.
Management—Optimize conditions environmentally by proper management of ventilation and heating based on the structure type.

Cracked, leaking cucumber fruit.

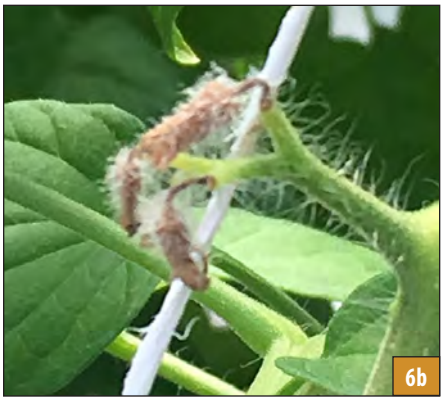


Blotchy fruit external appearance (a) and internal necrosis (b).

Curved cucumber fruit.

5. Curved fruits often occur in long English cucumbers when a leaf or a stem interferes with elongation of young, developing fruit. It can also be associated with improper irrigation and fertility management. Cucumbers developing close to the ground or top of container can also become curved.
Management—Prune cucumbers developing close to soil surface; do not allow longer English cucumbers to develop closer than 15 to 18 inches. Properly manage irrigation and fertility.

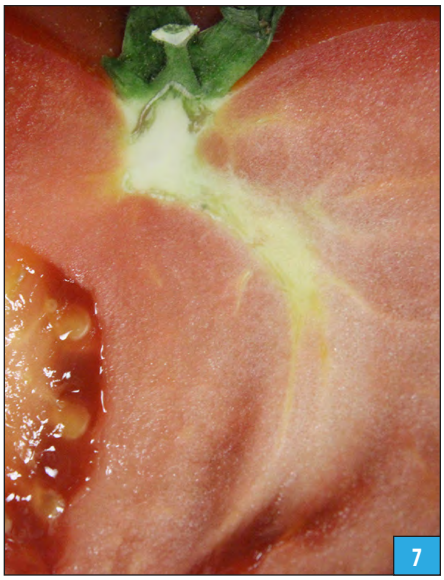
6. Flower drop/fruit abortion can be due to many conditions in protected structures, such as extreme heat, water stress, and fruit load. Flowers can also drop due to low light levels and relatively high nitrogen fertility.



Aborted cucumber fruit (a) and aborted tomato flowers (b).

Management—Adjust planting dates to avoid seasonal low light levels during flowering. Insure proper fertility and water management for crops when temperatures are high. As much as possible, modify the structure environment to provide optimum growing conditions for the crop.

7. Green core occurs when tomato fruit centers become hard and vegetative; normal red flesh fails to develop in that portion of the fruit. It is often associated with cool temperatures, low light levels, and excessive nitrogen fertilization.
Management—Manage structure environment to provide ideal temperature levels as much as possible. Maximize light by preventing condensation formation and removing shade cloth when sunlight is limited during cooler seasons of the year.



Internal green core on tomato.

8. Interveinal chlorosis is often seen on tomatoes and sometimes peppers during heavy fruit set. It appears on the lower leaves (older growth) as yellowing between the leaf veins. This is attributed to a magnesium deficiency in the plant that may be caused by a magnesium deficiency in the soil, but also may be caused by low soil pH (below 6.0) which makes magnesium less available to the plant. It also may be caused by excess potassium in the soil which causes reduced uptake of magnesium.
Management—Conduct annual soil testing several months prior to planting as soil pH alterations take time. A soil test will also indicate whether magnesium applications are necessary. Avoid excessive applications of phosphorus. During the growing season, a foliar/tissue test will indicate a deficiency in the plant. If a deficiency exists, magnesium oxide or magnesium sulfate may be applied.

Interveinal chlorosis (yellowing between the leaf veins) on tomato (a). When it occurs in the lower (older) leaves, it is often a symptom of magnesium deficiency in tomatoes (b).

9. Leaf roll symptoms include cupping of the lower leaves of tomato plants so that the margins are touching with no leaf discoloration. If plant stress is reduced, leaves with unroll. However, if stress factor persist, leaves further up the plant (and in rare cases the entire plant) with roll. Leaf roll can sometimes resemble symptoms caused by viruses, but it is physiological disorder that is not completely understood. The severity of leaf roll is often attributed to different cultivars. Indeterminate tomato plants bred to produce high yields are considered the most susceptible. Other causes include excessive pruning, excessive soil moisture combined with high air temperatures, and high nitrogen levels. Plant growth, fruit yield, and fruit quality are not generally affected.

Management—Avoid pruning when temperatures are high and avoid over-pruning. Maintain consistent, uniform soil moisture. Try maintaining temperatures below 95ºF and consider using shade cloth.

Tomato leaf roll, also known as leaf curl.

10. Marginal leaf burning and **marginal yellowing** occur on cucumbers grown in protected structures. It is associated with excess salt in the soil or soilless media. Excess salt can also cause stunted growth and low yields in other vegetable crops, such as tomatoes.

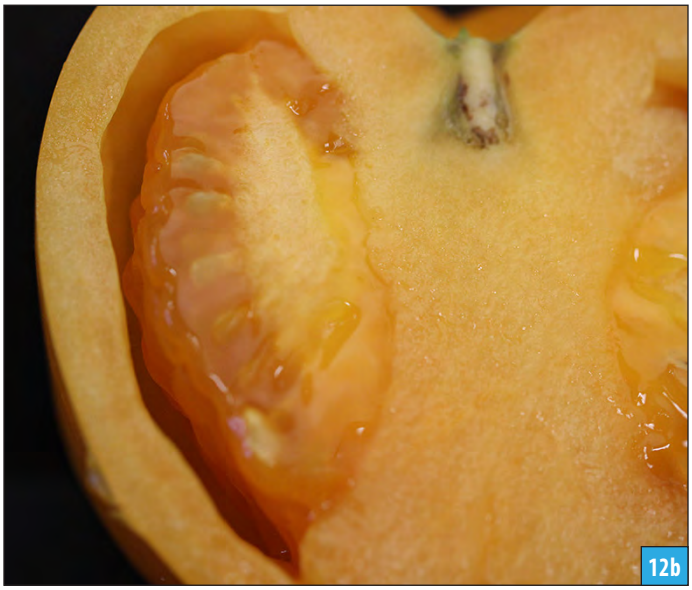
Management—Properly manage fertility, avoiding over-fertilization. Requesting a soluble salts or electroconductivity test on soil samples will provide information on soil salinity. Frequent tissue tests can help manage nutrient applications during the growing season. Periodically leach soil with fresh water to help remove some excess salt; however, effectiveness will vary based on soil type or soilless media. When it is time to replace the cover on the tunnel (approximately every 4-5 years), leave the tunnel uncovered through the winter to allow for weathering and rain to leach salts through the soil profile.

Marginal leaf yellowing on English cucumber foliage resulting from excess salt.

11. Pollutants, such as ethylene, sulfur dioxide, and nitrogen oxides, can cause plant injury that may be confused with herbicide injury. These pollutants can be generated by wood-fired boilers or natural gas/propane heaters. When heaters are used in protected structures, gases can build-up to damaging levels. Pollutants can also enter from exterior boilers as well. Symptoms of ethylene injury include distortion, yellowing, stunting, and flower/bud abortion. Other pollutants can cause flecking (typical of ozone injury) and/or burning of leaves and fruit.
Management—Regularly inspect heaters and maintain them in good working condition. Make sure heaters exhaust properly so pollutants are not trapped in structures.

12. Puffiness of tomatoes causes fruit to appear flattened on one or more sides and partially hollow inside. It can be attributed to an interaction of various factors during winter and early spring conditions, including low light levels, high fertility, and poor pollen viability.
Management—Choose varieties not prone to this disorder. Proper nutrient management and maximizing light penetration is critical. For structures with two layers of polyethylene, use outdoor air to inflate layers, rather than air from inside the structure; this prevents condensation formation between layers, which can reduce light.

Pollutants from heater causing damage to tomato plants.



Puffiness of tomato fruit external symptoms (a) and internal symptoms (b).

13. Yellow shoulder appears as yellow or pale orange around the stem of tomato fruit. Yellow shoulder may appear as delayed ripening, but is an actual disorder where part of the fruit will not turn red. Prevention is crucial as it occurs early in fruit development. The exact cause of yellow shoulder is unknown. However, it is thought to be related to potassium, magnesium, and calcium levels.

Management—Avoid excessive applications of magnesium. Manage foliar potassium levels by applying sufficient potassium prior to planting and maintaining consistent soil moisture. For mid to late summer tomatoes, consider using a 30% shade cloth.

Yellow shoulder.

14. Zippering is characterized by the presence of brown tissue (resembling a zipper) running down the sides of tomato fruit, often from the stem to blossom end. Zippering is the result of a flower anther remaining attached to newly forming fruit. It may be associated with incomplete shedding of lower petals when fruit is forming.

Management—Select varieties that do not seem prone to zipper.

Zipper scar on green tomato fruit.

Diseases

Aboveground Diseases

Any of the bacterial diseases can become significant greenhouse issues if bacteria are introduced via infested seed, transplants, or trellis materials. Thus, bacterial diseases are of particular concern for transplant producers or growers starting their own plants from seed. These pathogens can spread from initially infected plants through splashing water or by normal trellising activities. Transplants showing symptoms of bacterial diseases should never be set in the field or production greenhouse.

15. Bacterial canker (*Clavibacter michiganensis* subsp. *michiganensis*) causes wilting and marginal browning or necrosis (called 'firing') of tomato foliage; necrotic tissue may have a yellow border; leaves tend to curl upward. Elongated, tan lesions may also appear on tomato stems and petioles; lesions split and stem piths become grainy or pitted. Small (roughly 1⁄16 inch in diameter) raised lesions with white margins (called 'birdseye' spots) may appear on fruit. Seed infested with this bacterial pathogen, as well as contaminated, carried-over trellis materials, are sources of inoculum.

Management—Sanitation (debris removal and use of thoroughly disinfested trellis materials) is the most effective management tactic. Use pathogen-free seed and transplants. Apply labeled bactericide sprays to suppress secondary infections.

15a

15b

15c

15d

15e

Bacterial canker causing marginal browning (a); "firing" (b); pith necrosis (c); stem canker (d); and fruit spotting (e).

16. Bacterial speck (*Pseudomonas syringae* pv. *tomato*) results in small, circular, brown spots on stems, foliage, and fruit, primarily on tomatoes. Spots on foliage may be surrounded by a yellow border. These lesions coalesce to form large blighted areas in the plant canopy; defoliation may occur in severe cases. Very small specks, which may be sunken or very superficial, appear on green fruit. This disease tends to be more severe under cool temperatures.
Management—Use transplants started from pathogen-free seed. Follow good sanitation practices. Apply a labeled bactericide to reduce secondary spread.

16a

16b

Bacterial speck on tomato foliage (a) and fruit (b).

17. Bacterial spot (*Xanthomonas* spp.) occurs as spots on foliage, stems, and fruit of peppers and other solanaceous crops. Foliar lesions begin as small, circular, brown spots and may take on a wet appearance. These lesions may coalesce to form large blighted areas, which may also follow leaf veins. In severe cases, plants become defoliated, fruit drops, and flowering may be reduced or halted altogether. Lesions on green fruit develop as raised blisters about ¼ inch in size with a scabby appearance. This disease is favored by warm/hot temperatures. Contaminated seed and reused, unclean stakes are initial pathogen sources. Overhead irrigation and trellis injuries spread the bacteria among plants.
Management—Use disease-free transplants and practice sanitation as the primary management tactics. Apply labeled bactericide sprays to manage secondary spread.

18b

17a

18c

18d

Bacterial spot on tomato fruit (a); tomato foliage (b); banana pepper fruit (c); and bell pepper leaf (d).

Early blight on tomato foliage in planting (a) and close-up of lesions (b, c).

18. Early blight (*Alternaria tomatephila*) may occur in structures where tomatoes and other solanaceous crops are planted in ground beds without rotation or near open sidewalls. Leaf, stem, and fruit symptoms may occur. Foliar lesions are tan-to-brown with concentric ring patterns. Older leaves are usually affected first, but the disease will spread to newer growth under favorable conditions. Extensive blighting and loss of foliage can result. Fruit lesions are brown-to-gray, with a concentric ring pattern and often occurring at the stem end of the fruit. **Management**—Rotate to non-solanaceous crops. Apply labeled fungicides at regular intervals.

19. Gray mold (*Botrytis* spp.) occurs in structures with prolonged high humidity. This disease typically affects injured tissue and debris first, then spreads into the actively growing crop, including leaves, stems, and fruit. Lesions are tan-to-brown; abundant masses of gray spores form on the surface of diseased tissues. In advanced cases, overwintering structures called sclerotia may also develop. The gray mold pathogen has a very wide host range and can infect most vegetable crops and ornamentals.
Management—Reduce humidity by increasing air flow and eliminating standing water. Trellis plants carefully to avoid injuries. Remove fallen and diseased plant material from structures. Spray with a labeled fungicide on a regular schedule.

Botrytis gray mold fungus sporulating on tomato leaf and spent blossom (a), leaf (b), and stem (c); and on lettuce stem (d).

Leaf mold on tomato foliage (a) and pathogen sporulation (b).

20. Leaf mold (*Passalora fulva*) occurs primarily on tomato plants grown in structures with high humidity and cool temperatures. Light green to yellow spots appear on upper leaf surfaces, while a velvety green-brown layer of spores develops on undersides and rarely on upper leaf surfaces. This disease often occurs with Botrytis gray mold; however, leaf mold sporulation is browner and more common on the underside of leaves, while gray mold sporulation may occur anywhere on plants.

Management—Resistant varieties are available for some pathogen races. Reduce humidity by increasing air flow and eliminating standing water. Trellis plants carefully to avoid injuries. Remove dead plant material from structures. Spray labeled, systemic fungicides on a regular schedule.

Powdery mildew on tomato foliage (a, b) and petiole (c).

21. Powdery mildew (various species) affects nearly all vegetable crops, yet the causal fungus usually differs by plant host. Co-occurrence on multiple greenhouse crops occurs because the disease is benefited by high humidity, but low free water on plant surfaces, and sometimes low light conditions. This disease is characterized by the presence of a white powdery fungal growth appearing on upper and lower leaf surfaces, as well as stems and petioles. Over time, necrotic areas form, resulting in blighting of affected leaves which may also curl. While powdery mildew rarely affects vegetable fruit directly, it can significantly reduce yields due to lowered rates of photosynthesis in leaves.

Management—Increase air flow within structures and decrease humidity. Apply labeled fungicides on a regular schedule.

22. Septoria leaf spot (*Septoria lycopersici*) may occur in protected structures where tomatoes are cropped in the same soils year after year, or disease may initially begin near open sidewalls. Circular brown lesions with tan centers appear on foliage. Small black specks (pycnidia) are often found in centers of older lesions. Disease begins in lowest leaves and can progress up plants. Complete defoliation may result when disease is severe. Fruit are not affected; however, lesions may develop on stems under high disease pressure.

Management—Practice crop rotation. Apply labeled fungicides on a regular schedule. Remove infected crop debris promptly at season end.

Septoria leaf spot on tomato foliage in planting (a) and close-up (b).

23. Southern blight (*Sclerotium rolfsii*) typically causes lesions at or near the soil line, with white, fanlike fungal growth (mycelium) often evident on plant stems and expanding into surrounding soil. Numerous spherical fungal resting structures (sclerotia) roughly the size of mustard seeds can be found on the surface of the mycelia. Sclerotia initially appear white, but become tan or reddish brown as they mature. This pathogen overwinters in soil as sclerotia and can infect numerous different vegetable and ornamental crops.

Management—Fungicides may only be suppressive. Rotate to non-host crops. Deep tillage to bury sclerotia may hasten their decay. Consider fumigation or solarization.

Southern stem blight sclerotia and mycelia on tomato stem (a) and on soil around infected pepper plant (b).

Sclerotinia white mold/timber rot on trellised cucumber (a) and carrot (b); fruit drop on tomato (c); black sclerotia in decayed tomato fruit (d) and within a tomato stem (e).

24. Timber rot/white mold/drop (*Sclerotinia* spp.) can affect most vegetable crops. Infections girdle stems, eventually killing whole plants or causing damping off in leafy greens. White mycelium covers affected tissue under humid conditions; under drier conditions, elongated lesions appear bleached or tan. Infected fruit become limp and rotten; this phase occurs most commonly on tomatoes. Dark brown to black overwintering structures (sclerotia) are often formed on and within diseased tissues.

Management—Remove diseased plant parts or entire plants, as well as sclerotia; burn infected debris or dispose of in uncropped areas far from structures. Maintain a weed-free border around structures. Apply labeled fungicides or biocontrol products preventatively where this disease has previously been a problem.

Tomato spotted wilt in planting (a); on foliage (b, c, d); and on fruit (e).

25. Tomato spotted wilt virus (TSWV) causes a number of different symptoms on a wide variety of vegetable plants; it is particularly localized to young foliage and fruit. Foliar symptoms can include dark circular lesions, ringspots, and bronzing; infected fruit show ring spots, discoloration, malformation, and/or poor fruit set. TSWV can persist in association with ornamental plants, many weeds, and thrips in greenhouses. Thrips are the primary vector, moving TSWV from plant to plant.

Management—Carefully inspect plants prior to bringing them into structures to prevent introduction of disease. Aggressively manage weeds and other non-crop plants in and around agricultural structures. Monitor for thrips and manage their populations (see 38).

Fusarium wilt on tomato plants (a) and vascular discoloration (b).

26. Verticillium wilt (*Verticillium* spp.) and **Fusarium wilt** (*Fusarium* spp.) are caused by common soilborne fungi that do not readily produce airborne spores. Entire plants may wilt, or wilt may be confined to only one side of the plant; leaves become chlorotic (yellow). Cutting through infected stems reveals a brown discoloration of the vascular tissue (xylem). Fusarium wilt is favored by warm temperatures, while cooler conditions favor Verticillium wilt. These fungi persist in soils from year to year and some species may infect multiple plant species. **Management**—Select resistant cultivars when growing plants in infested soils. Rotate to a non-host crop. Consider fumigation or solarization.

Root Diseases

27. Fusarium crown and root rot (*Fusarium oxysporum* f. sp. *radicis-lycopersici*) of tomato is caused by a different *Fusarium* species than the pathogen causing Fusarium wilt. This soilborne disease advances more slowly than Fusarium wilt, though roots and stems still show extensive discoloration. Plants eventually wilt, but this may not occur until fruit bearing stage. Cracked cankers, sometimes with sporulation, may become evident on plant stems at the soil line. **Management**—Plant only resistant varieties in soils known to be infested. Avoid physically damaging plants. Rotate to a non-host. Fumigation or solarization may need to be considered.

Wilting due to Fusarium crown and root rot (a); discoloration in lower stem (b); lesion at stem base (c).

28. Pythium root rot (*Pythium* spp.) causes brown, rotting roots. Stem constrictions may occur at the soil line, sometimes with a lesion extending upward. Like other root rot diseases, plants may be stunted, exhibit nutrient deficiency symptoms, and suffer reduced yields. Pythium species are water mold pathogens with very wide host ranges.

Management—Increase soil drainage and avoid overwatering. Avoid introduction of natural soil into hydroponic systems. Use approved soil- or media-applied fungicides labeled for *Pythium* spp.

Pythium root rot (left) and healthy (right) watermelon transplant roots.

29. Rhizoctonia root rot (*Rhizoctonia solani*) is caused by a fungus that overwinters in soils and in association with crop debris. Similar to other root rots, roots decay and turn brown; however, Rhizoctonia lesions on roots and lower stems are often reddish-brown in color. *Rhizoctonia* also has a foliar phase on select crops in Kentucky, notably beans, leafy greens, and tobacco.

Management—Practice crop rotation and minimize overwatering. Apply labeled fungicides to suppress disease. Consider fumigation or solarization on severely infested sites.

Rhizoctonia root rot on beet (a), cabbage (b), and bean (c).

Root knot nematode symptoms on summer squash roots.

30. Root knot nematode (*Meloidogyne hapla* and *M. incognita*) infects a broad range of host plants. Aboveground symptoms include stunting, chlorosis (yellowing), and reduced yields; roots show characteristic knots or galls. Root knot nematodes are microscopic roundworms that can move through moist soils as juveniles. Mature female nematodes become permanently attached to plant roots and produce thousands of eggs that are released when females die.

Management—Select resistant varieties. Use non-fumigant nematicides for suppression. Immediately remove plant material, especially roots, from structures at season end. Consider fumigation, rotation with nonhosts, or solarization.

Insects and Other Arthropod Pests

Mites

31. Broad mite (*Polyphagotarsonemus latus*) has a wide host range that includes peppers and tomatoes. When present, they are in and around plant buds; however, due to their small size, confirmation requires a microscope. Broad mite injects a toxin that causes leaves and stems around buds to become deformed (often curling downward) and hardened; fruit may appear scarred. Eggs are clear with characteristic rows of raised white bumps that give them a jeweled appearance. Broad mites are more common at cooler temperatures.

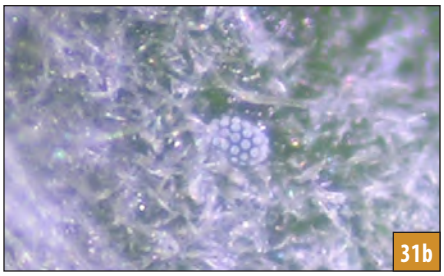
Management—At the first signs of damage, use an approved miticide labelled for broad mites; apply as needed. Miticides that control spider mites are not necessarily effective against broad mites.

Biological control—The predatory mite (*Amblyseius swirskii*) has been shown to be an effective predator of broad mites. Using a miticide is not recommended if using predatory mites for biological control. A small predatory lady beetle species (*Stethorus punctillum*) can also be purchased for mite suppression.

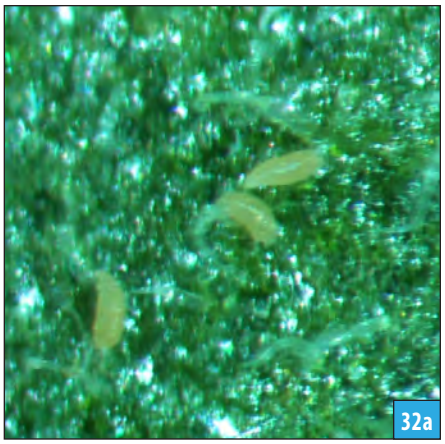
32. Tomato russet mite (*Aculops lycopersici*) causes bronzing of tomato stems and yellowing and drying of leaves. Damaged fruit remain small, turn brown, and have a russetted appearance. Symptoms move up plants from lower areas. Presence of this mite can only be confirmed with a hand lens (10X or greater) or microscope. Look for minute, cone-shaped mites on the green tissue. While this mite feeds on various solanaceous vegetables, damage has only been observed on tomato in Kentucky.

Management—Watch for characteristic damage; once tomato russet mite is confirmed, treat with an approved miticide. Miticides that control spider mites are not necessarily effective against russet mites. Evaluate miticide effectiveness by tagging the limits of stem bronzing on a plant and monitoring it for additional damage. Remove alternate hosts, such as nightshades, bindweed, and morningglory, from in and around structures.

Biological control—If your structure has a history of tomato russet mite infestations, consider releasing *Amblyseius fallacis* predatory mites.



Broad mites (a); eggs (b); deformed, hardened plant tissue (c); and fruit injury to pepper (d).



Tomato russet mites (a); bronzed, greasy appearance to stems (b); and undersized, dark, russetted fruit (c).

33a

33b

33c

33d

Two-spotted spider mite (a); stippling damage to leaf (b) and fruit (c); and webbing on severely damaged leaves (d).

33. Two-spotted spider mite (*Tetranychus urticae*) is the most common mite occurring on greenhouse and high tunnel vegetable crops; it will feed on hundreds of plant species, particularly during hot, dry conditions. Adult mites are less than 1 mm in size and can vary from light green to straw-colored; a large dark spot is present on each side of the body. Eggs are clear and spherical. Spider mites cause stippling (tiny light-colored spots) on leaves and fruit as they feed with their piercing-sucking mouthparts. Webbing between plant structures may be noticeable when populations are large.

Management—Release predaceous mites for biological control or apply foliar miticides.
Biological control—Two species of predatory mites (*Phytoseiulus persimilis* and *Amblyseius fallacis*) have been shown to be very effective for two-spotted spider mites.

Potato aphids (a); melon aphids (b); green peach aphids (c); comparison of size and shape of potato aphid (center) and melon aphids (d).

Lacewing larvae use large sickle shaped mouthparts to feed on aphids (e). Adults of some species of lacewings feed on aphids prior to laying eggs (f). An adult stingless wasp has emerged from this aphid mummy (g). This life stage indicates that the wasp has successfully parasitized the aphid.

Insects

34. Aphids (Family Aphidae) occuring in high tunnels include green peach, melon (cotton), and potato aphids. Aphids feed with piercing-sucking mouthparts and are vectors of several potyviruses. Aphid bodies are pear-shaped to round with two tailpipe-like projections (cornicles) near the end of their abdomens. Some adults are winged; others are wingless. Sugary honeydew and black sooty mold fungal growth are often found underneath aphid infestations. Large populations will turn leaves yellow, stunt plants, and reduce yields.

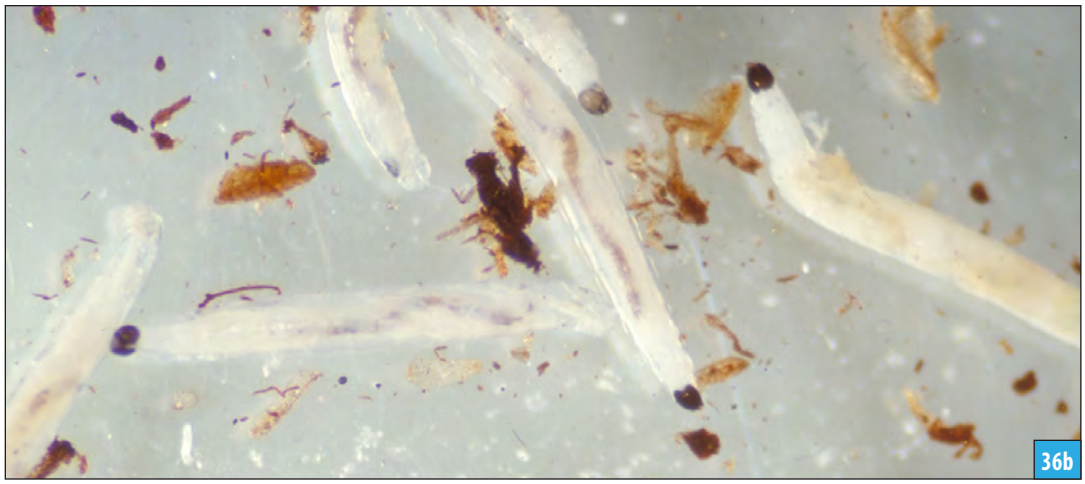
Management—Release predators or minute wasp parasitoids, or use foliar insecticides. Banker plants can be used to sustain natural enemies. Eliminate weeds in and around structures. Monitor for winged aphids with yellow sticky cards (see 38a). Avoid over fertilizing plants with nitrogen.

Biological control—Predatory lacewing eggs and/or larvae can be released for aphid suppression. Also available is a predatory fly (*Aphidoletes aphidimyza*). A number of species of tiny stingless wasps (aphid parasitoids) are commercially available for several different aphid species. For example, *Aphidius colemani* was recently released in a Kentucky greenhouse for suppression of melon aphids. The release of these wasps provided season long suppression of melon aphids in this structure. It is critical to identify the species of aphid pest to determine the most appropriate species of stingless wasp to release.

Yellow-striped armyworm in tomato fruit.

35. Caterpillars (various species), including yellow-striped armyworm and corn earworm, can damage foliage and/or fruit, depending on the species and type of vegetable grown. Caterpillars feed with chewing mouthparts, thus, holes in leaves and fruit are signs of possible activity. Adults are moths, which do not damage plants.

Management—Use screens over ventilation windows to prevent moth entry. Avoid placing security lights, which can attract moths at night, near structure entrances or windows. Sprays using *Bacillus thuringiensis* to control caterpillars are compatible with biological control methods.



Fungus gnat adult (a) and larvae (b).

36. Fungus gnats (Family Sciaridae) are small, delicate, dark-bodied, slender flies. Adult flies are about 1⁄10 inch in size and have long antennae, slender legs, and a tapering spindle-shaped abdomen. Larvae are legless with white bodies and dark head capsules about the size of poppy seeds. Larvae, which primarily feed on fungi, algae, and organic matter, require continuously wet conditions to develop. While adult flies are not damaging, large numbers of larvae can injure roots and stunt plant growth.
Management—Controls are directed toward larvae rather than adults. Avoid continuously wet soil/media. Eliminate standing water and repair irrigation leaks. Place raw potato slices on soil surfaces to attract and monitor for larvae.
Biological control—Use entomopathogenic nematodes and predatory mites or apply soil drenches containing *Bacillus thuringiensis israelensis*. Other options include predatory mites.

Brown stink bug (a); brown marmorated stink bug (b); green stink bug (c); and stink bug damage to tomato (d).

37. Stink bugs (*Euschistus* spp., *Chinavia hilare, Halyomorpha halys*) are ½ inch to ¾ inch in size and shield-shaped. Stink bugs feed with piercing-sucking mouthparts and cause off-color corky areas under skins of tomato and pepper fruit; these symptoms are called 'cloud spots.' When disturbed, stink bugs give off an odor similar to that of crushed cilantro.
Management—Use screens over ventilation windows to prevent stink bug entry. Eliminate weeds around the outside of high tunnels. When stink bugs are detected, use foliar insecticide sprays as needed to prevent fruit injury.

Yellow sticky card for monitoring thrips and other insect pests (a). Thrips (b); damage to leaves, along with associated insect waste material (tar spots) (c).

38. Thrips (Family Thripidae) are narrow, tiny insects (about 1⁄20 inch in length) that have four narrow wings fringed with hairs. While they can live in flowers and buds, thrips leave characteristic damage on leaves with their rasping mouthparts. Silvery to brown feeding scars about ¼ inch in size or less, along with black tar spots (their waste material), are diagnostic. Thrips can vector tospoviruses, including tomato spotted wilt virus (see 25).

Management—Early detection is important. To monitor, use yellow sticky cards hung just above crop canopies (a minimum of four per high tunnel) and/or tap plant parts over white paper to inspect for thrips. Eliminate weeds in and around structures. Approved insecticides are another management option.

Biological control—Predatory mites can be used for biological control of thrips. *Neoseiulus* (*Amblyseius*) *cucumeris* and *Amblyseius swirskii* are commercially available.

Whitefly eggs (a); greenhouse whitefly (b); banded wing whitefly (c); sweetpotato whitefly nymph (d); sweetpotato whitefly (e); and tiny black specks of sooty mold growth on whitefly honeydew secretions (f). The tiny yellow Eretmocerus (g) are stingless parasitic wasps that lay eggs inside silverleaf whitefly nymphs.

39. Whiteflies (*Bemisia tabaci, B. argentifolii, Trialeurodes vaporariorum, T. abutilonea*), such as sweetpotato, greenhouse, and banded wing whiteflies, infest undersides of leaves. Greenhouse whitefly holds its wings flat on its back; sweetpotato whitefly holds its wings vertical and roof-like; and banded wing whitefly has prominent gray bands on its front wings. Whitefly eggs are often laid in arcs or partial circles on undersides of leaves. Immature whiteflies are sedentary, scale-like, light yellow in color, and found on middle and lower leaves. White fly feeding can cause leaf yellowing and generate ripening disorders with tomatoes. *Bemisia* whiteflies can vector begomoviruses. Whiteflies produce honeydew, which can result in sooty mold fungal growth on plant surfaces.

Management—Eliminate weeds in and around structures. Monitor for whiteflies with yellow sticky cards (see 38a). Use commercially available minute wasp parasitoids and predators (match with the species of whiteflies present). Apply systemic and foliar insecticides.

Biological control—Correct identification of the species of whitefly infesting your structure is critical in selecting a biological control organism. Two species of tiny stingless wasps can be purchased for release against whiteflies, *Encarsia formosa* (greenhouse whitefly) and *Eretmocerus eremicus* (silverleaf or sweet potato whitefly). A predatory lady beetle (*Delphastus catalinae*) can also be released for whitefly suppression.

High Tunnel Weekly Monitoring Form

Name: _____ Date: _____ Greenhouse/High Tunnel: _____ Conditions: _____

General Walk-through Observations									
Section/Row	Honeydew	Aphids	Thrips	Whiteflies	Fungus gnats	Spider mites	Russet Mites	Other:	Other:
Total									

Yellow Sticky Cards							Map
Location	Winged aphids	Thrips	Whiteflies	Fungus gnats	Other:	Other:	
Total							

Plant Inspections									
Section	Aphids	Thrips	Whitefly adult	Whitefly nymphs	Fungus gnats	Shore flies	Spider mites	Russet Mites	Other:
Total									

Herbicide Injury and Weeds

2-4, D (a) and glyphosate (b) injury to tomato plants.

40. Herbicide drift can be an issue for high tunnel and greenhouse growers. Growth regulator herbicides, such as 2-4,D, may easily volatilize and become trapped inside structures. If backpack sprayers are used at a much higher pressure than is recommended for herbicides, the smaller droplets that form are prone to drift. Typical growth regulator herbicide injury includes malformation and irregular growth habit. Glyphosate (Roundup) can also drift and cause damage to sensitive plants. Most herbicide damage will occur on the upwind side of structures.

Management—If possible, avoid using liquid herbicides anywhere on the same property as structures. If they must be used on nearby fields, apply herbicides only on calm days with closed walls. Discuss herbicide usage with neighboring growers to enlist their cooperation.

41. Weeds within tunnels compete for light, nutrients, and water; increase the incidence of insect and disease problems; and can reduce air circulation. Because high tunnels are considered greenhouses in Kentucky, few herbicides can be used within structures, except when plastic coverings have been removed for replacement.

Management—Before constructing tunnels, be sure perennial weeds are under control at the

Weeds within tunnels (a); white woven reusable ground cover in row middles (b); and Soil solarization of moist soil for managing weeds (c – next page).

site. During the growing season, weeds can be managed within structures by using hand tools or a walk-behind rototiller. Use mulch (black plastic, paper, or white-on-black-plastic) in production areas. Straw (not hay), which should not contain seeds, can also be used as mulch. Do not allow weeds around structures to go to seed. Only use compost that has reached high enough temperatures so weed seeds are killed. If no crops are present during summer, structures can be closed and soil solarization can be implemented. Soil solarization heats soil to temperatures detrimental to weed seeds below the surface. Weed seeds will die if high enough temperatures are reached. Different weeds are tolerant to different temperatures.

42. Weeds around tunnels increase the chance of weed seeds entering structures, hamper airflow, and provide potential reservoirs for insects and diseases. A vegetation-free strip should be maintained around perimeter of structures.

Management—Remove or mow vegetation in outside perimeter. Apply gravel, plastic mulch, landscape fabric, or natural mulch near exterior walls.

Gravel on the ground surrounding structure exterior.

General IPM Best Management Practices

Prevention

- Manage perennial weeds at high tunnel sites before construction
- Plant seed/transplants that have been screened for pathogens and appear disease-free
- Use new commercial transplant media from a reputable source
- Use insect screen to cover openings
- Inspect new plants coming into structures for pests and diseases
- Avoid wearing brightly colored clothes that could attract certain insects
- Apply mulch to inhibit weeds (organic mulches need to be free of weed seeds and other propagules)
- Avoid herbicide applications near tunnels
- Close and remove bumblebee colonies prior to use of pollinator-toxic insecticides; store bees in a shady location for a day before returning them to the structure

Sanitation

- Eliminate all weeds in and around structures (20-foot perimeter)
- Maintain a 2-week plant-free period prior to each new crop cycle
- Thoroughly sanitize all stakes and trellis materials between crops
- Remove and destroy or dispose of fallen plant debris
- Do not allow clippings from mowing to blow into tunnels

Insect screening over greenhouse openings and gravel around exterior.

Environmental management

- Avoid excessive watering or use of nitrogen
- Avoid temperature extremes
- Reduce leaf wetness by using drip irrigation and repairing sagging or leaking ceilings
- Use summer solarization to destroy weed seeds and reduce soilborne disease pressure

Monitoring

- Use yellow sticky cards to monitor for insect pests; check cards regularly
- Frequently inspect plants for signs and symptoms of pests and disease
- Watch for weeds and remove; do not allow weeds to go to seed in or around structures
- Record all scouting observations and maintain for reference in future years

Biological control

- Consider using biological control for reoccurring pests
- Avoid using pesticides damaging to beneficial insects and mites
- Evaluate compatibility of biological control with other pest and disease management
- Best used when pest densities are low
- Correct identification of pest species is required
- Will not completely eliminate the pest(s)

Chemical

- Only apply pesticides as necessary
- Apply only those pesticides labeled both for the crop and for greenhouse use
- Never exceed the application rate or season limit of any applied pesticide
- Rotate pesticide modes of action to manage resistance in populations

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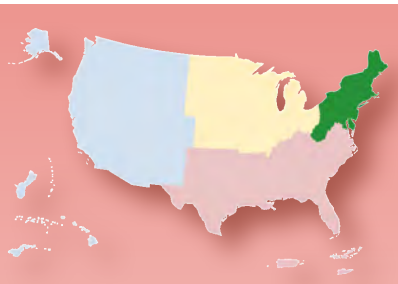

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For more information, go to www.sare.org/project-reports and search by project number.

Written by Pat Michalak

SARE Sustainable Agriculture Research & Education

www.sare.org

Sustainable Pest Management in Greenhouses and High Tunnels

Geographic Adaptability: The techniques discussed here apply primarily to vegetables produced in unheated greenhouses and high tunnels in the northeastern United States, but may also be adapted to production in other regions with similar climates and pest populations.

Introduction

Growers using greenhouses in which temperature, light and relative humidity are controlled have relied for many years on releases of natural enemies to manage aphids, thrips and two-spotted spider mites. However, many of the natural enemies used to manage these pests in heated structures are too sensitive to swings in air temperature and relative humidity to be used in cool structures such as minimally heated greenhouses and unheated high tunnels. Because these season extension tools are widely used by organic and sustainable vegetable growers, SARE funded a project to study the efficacy of biological insect control in minimally heated greenhouses and high tunnels. Researchers conducted 23 case studies involving tomatoes, cucumbers, eggplants, winter greens and peppers grown in greenhouses and high tunnels at nine locations in upstate New York from 2007 to 2009. This fact sheet reports the results and provides detailed advice on how growers can use natural enemies to manage insect pests in minimally heated greenhouses and unheated high tunnels.

Note: In this fact sheet, a number in parentheses refers to one of 23 case studies from Reid, J. 2010b. For more information, see *Resources and References* (page 10).

PUBLISHED MAY 2014

Biological Control

Biological control—the suppression or eradication of crop pests using their natural enemies—is a tool used by growers to manage plant pests. Biological control offers many benefits:

- Compared to repeated applications of organic sprays, releasing natural enemies requires less time.
- Once established, natural enemies work around the clock.
- When using natural enemies, re-entry and pre-harvest intervals are unnecessary.

In this study, researchers found that it was important to select the correct species of natural enemy, because most have narrow preferences for air temperature, relative humidity and pest hosts. The categories of natural enemies used in this study were predatory mites, parasitic wasps and the predatory minute pirate bug (*Orius insidiosus*).

Predatory Mites

Predatory mites feed directly on insect pests and then reproduce independently. Some predatory mites are generalist feeders because they can prey on several types of pests, while other mites are specific feeders that prey on only one type of pest. The predatory mites used in this study were the generalist feeders *Amblyseius californicus* and *Amblyseius cucumeris*, and the specific feeder *Phytoseiulus persimilis,* which preys on the two-spotted spider mite.

Parasitic Wasps

Parasitic wasp adults do not prey on plant pests; instead they lay their eggs inside the target pests. The pests are killed as the newly hatched wasp larvae develop inside the pest's body. Parasitic wasps need pests in order to reproduce. Growers using parasitic wasps need to know the species of their pests because parasitic wasps are very specific. In this study, *Aphidius colemani* and *Aphidius ervi* were used to manage aphids, and *Encarsia formosa* to manage whiteflies.

Predatory Minute Pirate Bug

The minute pirate bug (*O. insidiosus*) is a common predator of pests in most field-grown crops. It is a small (one-twelfth of an inch to one-fifth of an inch long) flying insect. The minute pirate bug is used to manage thrips, whiteflies, spider mites, aphids, psyllids, lygus bugs and small caterpillars.

How to Manage Crops for Natural Enemies

Most natural enemies need a specific temperature and relative humidity in order to be effective. This can be a problem in greenhouses and unheated high tunnels because these structures experience wide temperature and moisture fluctuations. Using natural enemies requires an understanding of the pest species, the temperature and humidity, the natural enemies themselves, the environment, and the grower's economic goals.

Scouting for Natural Enemies and Pests

Frequent scouting of the crop for pests is also necessary. Action levels for releases of natural enemies and effective release rates have not been established for every pest on every crop, so growers may need to establish their own guidelines.

A simple 10X to 20X hand lens is sufficient to identify most greenhouse pests and their natural enemies. To identify insects, hold the lens stationary in front of your eye while moving the plant or leaves in or out to focus.

Application

Many natural enemies attack only certain life stages (e.g., egg or larval stage) of their pests, therefore multiple releases may be needed to maintain pest suppression. To prevent pest infestations, release natural enemies early in the pest cycle when pest numbers are beginning to increase. For effective preventive releases, start early in the growing season and follow these steps:

1. Begin monitoring crops for pests as soon as environmental conditions are right for their development. Consult with your local Cooperative Extension personnel to track the development of pests at your location. You can also find this information on websites maintained by Cooperative Extension in your state. Just as crop plants develop at different rates within a county or region, the development of pests and their natural enemies will vary each year.
2. Determine the best method to use for scouting the pests on your crops, and then use the same method each week to track their development. Scouting methods are as simple as counting the number of aphids or mites found on 10 leaves, or recording the number of thrips found on yellow sticky cards placed at several locations around the greenhouse or high tunnel. While scouting, rate the amount of damage on new leaves.
3. Keep a record of the number of pests and their damage rating at each location.
4. When pest numbers or their damage rating begins to increase, order the appropriate natural enemies from your distributor. Be aware that distributors can take one to two weeks or more to process and ship your order. It is a good idea to familiarize yourself with your distributor's ordering policy well before you anticipate needing natural enemies. When your order arrives, follow the distributor's instructions for releasing the natural enemies.

5. Monitor the quality of the natural enemies by using a hand lens to check for activity. Stick with distributors who send natural enemies that are active and thriving after being shipped.
6. Learn to recognize the natural enemies you have released, as well as the signs that they are working. Commercial suppliers can provide you with pictures of the natural enemies you purchased.
7. If plants are heavily infested with pests, it may be necessary to apply a compatible pesticide to knock down their numbers before releasing the natural enemies that you have purchased. A knock-down spray of pure water is relatively harmless, but most other pesticides require a good understanding of the pests, pesticides, and natural enemies. Before using pesticides, read and follow label directions, and consult the Agricultural Use Requirements section for Personal Protective Equipment (PPE) and Restricted Entry Intervals (REIs). Researchers used knock-down sprays, in combination with natural enemies, to manage aphids (refer to Fig. 7 and Fig. 8).
8. Make sure there is no exposure to pesticide drift from adjacent areas and that residues are gone prior to releasing natural enemies. Pesticide residues on the crop or soil can remain toxic to natural enemies long after the pesticide was applied. To avoid residue problems, growers can use resources such as the *BioBest Sustainable Crop Management Side Effects Manual* or consult with their supplier for up-to-date information on the side effects of pesticide residues on natural enemies.

Management of Two-Spotted Spider Mites

Introduction

The most common spider mite pest in greenhouses and high tunnels in the Northeast is the two-spotted spider mite (*Tetranychus urticae*). This mite prefers hot, dry environments. It damages plants by puncturing plant cells and draining the contents of the cells, causing the leaves to become spotted or stippled. In the SARE study, the predatory mites *P. persimilis*, *A. californicus* and *A. cucumeris* were used to manage the two-spotted spider mite on tomatoes and cucumbers in greenhouses and high tunnels.

Researchers found that spider mite populations increase rapidly, and recommend releasing controls at the first sign of mites. They also found that it was useful to make a second release, use higher rates and/or release several generalist predators at one time.

FIG 1. Two-spotted spider mite damage on zucchini plant leaves. *Photo courtesy Whitney Cranshaw, Colorado State University, Bugwood.org #5369740*

FIG 2. Scanning electron image of two-spotted spider mite feeding on rose leaf. *Photo courtesy E. Erbe, USDA-ARS*

How to Scout for the Two-Spotted Spider Mite

Prevent spider mite outbreaks by scouting weekly and releasing natural enemies as needed. Look for the characteristic spotting on plant leaves (Fig. 1). All spider mites have four pairs of legs. The two-spotted spider mite has two prominent spots on the upper surface of its body (Figs. 2 and 3). Look for mites on the undersides of leaves. Also look for their silken webbing (Fig. 3).

Natural Enemies of the Two-Spotted Spider Mite

Phytoseiulus persimilis

Phytoseiulus persimilis, a highly specialized predator mite, works best at a temperature of 65 to 80 degrees F and a relative humidity of at least 60 percent. This predatory mite preys only on the two-spotted spider mite, so in the absence of the spider mite the predatory mite will perish. It can be cannibalistic when spider mite prey is unavailable. For this reason, highly specialized predators such as *P. persimilis*

FIG 3. Two-spotted spider mite and web. *Photo courtesy D. Cappaert, Michigan State University, Bugwood.org #5371009*

are difficult to use in preventive programs and are more effective after pest populations become established.

This predatory mite is one of the mainstays of greenhouse biological control programs for management of spider mites on vegetables and ornamentals, but the SARE-funded researchers found that in high tunnels the temperature and humidity fluctuated too widely to support this species except for several weeks in spring and summer (Table 1). *P. persimilis* was the natural enemy most commonly released to manage the two-spotted spider mite in the SARE study, but results were inconsistent.

In 2007, *P. persimilis* was released to manage the two-spotted spider mite on tomatoes grown in a greenhouse at one location (3). Because scouting began too late, this predatory mite was not effective in reducing pest numbers. In the years that followed, scouting began earlier in the season and this natural enemy was released earlier.

In 2008 and 2009, releases of *P. persimilis* (16, 9) at several locations provided some control of the two-spotted spider mite on both tomatoes and cucumbers. The two-spotted spider mite was successfully controlled on the tomato crop; however, on the cucumber crop the predatory mite provided some control but failed to eradicate the pest. In 2010, releases of *P. persimilis* successfully controlled the two-spotted spider mite on cucumbers in high tunnels (19, 20).

P. persimilis was also used to manage the two-spotted spider mite on eggplants in high tunnels in 2008. The pest mite population was reduced but not eradicated, yet the plants continued to grow and produced good quality fruit.

In 2010, releases of this predatory mite almost eradicated the two-spotted spider mite on heavily infested baskets of strawberry plants in a greenhouse. As the population of the predatory mite grew and became established on the crop, pest mite numbers declined.

Application

In tomatoes and cucumbers, release 1,000 mites per 10,000 square feet. Follow the instructions provided by your distributor, but in general, release *P. persimilis* at the first sign of an infestation of two-spotted spider mites. It may be necessary to remove heavily infested plants or apply a knock-down spray before releasing this predatory mite. After releasing, continue to monitor the mites as well as the predatory mites. Repeat releases as needed.

Amblyseius californicus

Amblyseius californicus is a general predator that is most efficient at a temperature of 60 to 80 degrees F and a relative humidity of at least 60 percent. It feeds on spider mites, thrips, aphids and other pests. It prefers the two-spotted spider mite, and will consume all life stages of this pest. This predatory mite can survive longer than *P. persimilis* in the

TABLE 1. EFFECT OF PREDATORY MITES ON CONTROL OF TWO-SPOTTED SPIDER MITES IN UNHEATED GREENHOUSES AND HIGH TUNNELS[1]

CROP[3]	SUCCESS RATING OF TWO-SPOTTED SPIDER MITE CONTROL WITH THE FOLLOWING PREDATORY MITES[2]		
	Phytoseiulus persimilis	*Amblyseius californicus*	*Amblyseius cucumeris*
Tomatoes	3.5; 3.5	-	-
Tomatoes in Greenhouses	0; 3	3; 4	-
	-	2.75 (combined release of *A. californicus* and *A. cucumeris*)	
Cucumbers	3; 2.5; 4.5	-	-
Eggplants	3	-	-
Strawberry Baskets	4	-	-

[1] 2007 through 2010
[2] Each number represents the success rating of control in one season at one of 19 case studies where 0 = control failed; 3 = pest was controlled; 5 = pest was eradicated.
[3] Crops were produced in high tunnels unless noted otherwise.

absence of prey and has been shown to successfully control the two-spotted spider mite in greenhouses and high tunnels.

The SARE study results indicated that *A. californicus* can be used in both greenhouses and high tunnels (Table 1). Researchers recommend the release of general predators such as *A. californicus* for preventive pest control. *A. californicus* can sustain itself better than *P. persimilis* because it can be released when pest numbers are still low and sustain itself on pollen, insects and mites while pest numbers are still growing. Releases of *A. californicus* controlled the two-spotted spider mite on tomatoes grown in greenhouses at several locations in 2008 (6, 7).

Application

Release this beneficial mite when a combination of pest species, such as two-spotted spider mites and thrips, are present and require action. Release 1,000 mites per 4,500 square feet of infested area on tomatoes, cucumbers and most other crops in greenhouses and high tunnels. Follow the instructions provided by your distributor, but in general, release *A. californicus* at the first sign of an infestation of two-spotted spider mites. It may be necessary to remove heavily infested plants or apply a knock-down spray before releasing the beneficial mite. After releasing, continue to monitor the two-spotted mites as well as the predatory mites. Repeat releases as needed.

Combination of Management Tools

Researchers recommend using a combination of tools to manage one or more pests at the same time, or when pest numbers are very high. Strategies can include spraying with a pesticide to knock down pest numbers, followed by releases of one or more species of natural enemies. A combined release of *P. persimilis* and *A. californicus* provided a low level of control of the two-spotted spider mite on tomatoes in a greenhouse at one location in 2009 (15).

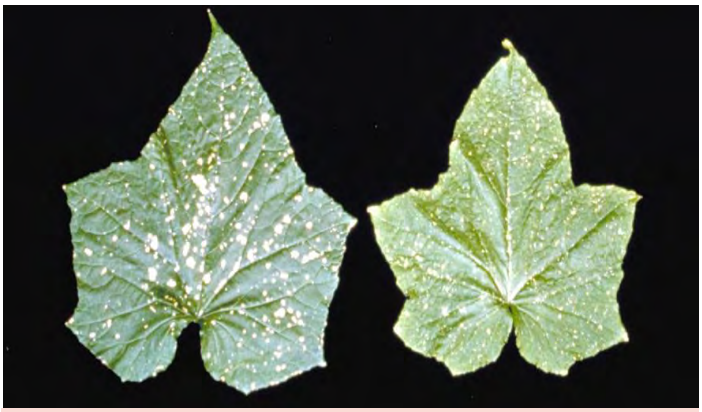

FIG 4. Thrips damage on cucumber: flower thrips (*Frankliniella*) with coarser pattern (left); onion thrips (*Thrips tabaci*) (right). *Photo courtesy Jack Reed, Mississippi State University, Bugwood.org #0660069*

FIG 5. Adult stage of western flower thrips. *Photo courtesy P.M.J. Ramakers, Applied Plant Research, Bugwood.org #5370035*

The release of *P. persimilis* and *A. cucumeris* also controlled the two-spotted spider mite and thrips, respectively, on tomatoes, cucumbers and blueberries in a high tunnel at one location in 2009 (16).

Management of Thrips

Introduction

The most common thrips in greenhouses and high tunnels in the Northeast are flower thrips (species of *Frankliniella*) and onion thrips (*Thrips tabaci*). Flower thrips damage flowers and leaves. Onion thrips are pests on several hundred host plants, including cucumbers, tomatoes, eggplants and peppers. Thrips reduce the yield of crops by puncturing plant cells with their mouthparts. They damage the leaves and blossoms of host plants as well as transmit viruses.

Thrips like dry conditions, so keep plants well watered and relative humidity high. Researchers examined the efficacy of two generalist predators, *A. cucumeris* (a mite) and *O. insidiosus* (the minute pirate bug), on controlling thrips on tomatoes and cucumbers in greenhouses and high tunnels.

How to Scout for Thrips

Prevent thrips outbreaks by scouting weekly and releasing natural enemies at the first sign of damage, or when first detected on sticky cards. Sticky traps may help to detect thrips up to a month before they are seen on plants. It is easier to find thrips damage than to find the actual thrips. Look for the characteristic white streaks or spots on leaves, flecked with black spots of feces (Fig. 4). Damage is often found on the lower leaves of cucumber and tomato. In sweet peppers, the damage first appears in the upper, youngest leaves. On vegetable flowers, thrips feeding makes silvery white streaks on the petals. Thrips do not leave behind silken webbing.

Thrips are difficult to identify without a hand lens. They have six legs and narrow wings and are often found with

TABLE 2. EFFECT OF NATURAL ENEMIES ON CONTROL OF THRIPS IN HIGH TUNNELS[1]

CROP	SUCCESS RATING OF THRIPS CONTROL WITH PREDATORY MITES AND MINUTE PIRATE BUGS[2]			
	PREDATORY MITES			MINUTE PIRATE BUG
	Phytoseiulus persimilis	*Amblyseius californicus*	*Amblyseius cucumeris*	
Cucumbers	-	-	4.75; 4; 4.5	
	-	-	5 (combined release of *A. cucumeris* and minute pirate bugs)	

[1] 2007 through 2010
[2] Each number represents the success rating of control in one season at one of 19 case studies where 0 = control failed; 3 = pest was controlled; 5 = pest was eradicated.

their wings folded, so they look like tiny brown flecks of peat moss on leaves and on sticky cards. Some specimens will have hairs on their wings when viewed with a hand lens (Fig. 5).

Natural Enemies of Thrips

Amblyseius cucumeris

Amblyseius cucumeris prefers a diet of thrips but is considered a generalist because it can survive on pollen and spider mites in the absence of thrips. *A. cucumeris* will work best at a temperature of 70 degrees F or above and a relative humidity above 65 percent.

Results indicate that *A. cucumeris* should be used to manage thrips in spring and summer crops of organic vegetables in high tunnels. In comparison with other predatory mites that prey on thrips, *A. cucumeris* costs less, has greater survivability and a broad range of prey, and works well when released preventively early in the growing season.

Preventive releases are especially important on cucumbers, which are more attractive to thrips than other common high tunnel crops. *A. cucumeris* is a generalist predatory mite, and it lends itself to preventive approaches because it can survive on pollen or other insect and mite pests in the absence of the target pest thrips. Control of thrips was consistent and this predatory mite was a repeated success story.

In 2009 and 2010, releases of *A. cucumeris* controlled thrips on cucumbers in high tunnels at several locations (14, 16, 19). Overall, thrips levels were reduced by an average of 85 percent after releases of *A. cucumeris* (Table 2).

Application

Follow the instructions provided by your distributor, but in general, release *A. cucumeris* at the first sign of an infestation of thrips. It may be necessary to remove heavily infested plants or to apply a knock-down spray before releasing the predatory mite. After releasing, continue to monitor the thrips as well as the predatory mites. Repeat releases of natural enemies as needed.

Orius insidiosus

Orius insidiosus (minute pirate bug) is a common generalist predator found naturally in many field-grown crops. It preys on thrips, whiteflies, spider mites, aphids and many other pests. It can survive on pollen in the absence of prey. The minute pirate bug will work best at a temperature of 70 to 90 degrees F and a day length of 11 hours or more.

Application

Make releases at any time, early or late in an infestation of thrips, because the minute pirate bug can control heavy infestations quickly. For preventive control, release one to two minute pirate bugs per plant in greenhouses. When treating a heavy infestation of thrips, aphids, or whiteflies release 500 minute pirate bugs per 250 square feet. Minute pirate bugs will move efficiently throughout the infested plants and will continue to kill even when they do not need to eat. After releasing, continue to monitor the thrips as well as the pirate bug.

Combination of Management Tools

Use a combination of tools to manage one or more pests at the same time, or when pest numbers are high. In 2007 (1), one release of minute pirate bugs together with three releases of the generalist predatory mite *A. cucumeris* eradicated thrips on cucumbers in a greenhouse (Table 2). Two releases of *A. cucumeris* made earlier in the season likely would have been sufficient.

Releases of *P. persimilis* and *A. cucumeris* successfully controlled the two-spotted spider mite and thrips on tomatoes, cucumbers and blueberries in a high tunnel at one location in 2009 (16).

Management of Aphids

Introduction

Many species of aphids can be found on vegetable crops in the Northeast. Low to moderate numbers of aphids are usually not harmful to vegetables. However, large populations

cause curling and yellowing distortion of leaves and stunting of shoots. Aphids can also transmit viruses to vegetable crops.

A. colemani and *A. ervi*, two pest-specific wasps that parasitize aphids, were used to manage a broad range of species on winter greens and peppers in high tunnels at several locations.

How to Scout for Aphids

Prevent outbreaks of aphids by scouting weekly and releasing natural enemies at the first sign of damage. Check plants regularly for aphids, including at least twice weekly when plants are growing rapidly. Look for the small, white flakes that are the cast-off skins of aphids. Many species of aphids cause the greatest damage when the temperature is from 65 to 80 degrees F. Aphids reproduce quickly, so catch infestations early. Once aphid numbers are high and they have begun to distort and curl leaves, it is often hard to reduce populations because the curled leaves shelter aphids from insecticides and natural enemies.

Aphids excrete a sugary, sticky liquid called honeydew, which promotes the development of black, sooty mold fungus on the leaf surface. Sooty mold is not pathogenic on the plant, but in severe infestations it can interfere with photosynthesis. Watch for honeydew on leaves, stems and other surfaces.

Aphids tend to be most prevalent along the upwind edge of fields and close to other sources of aphids, so scout these areas. Many aphid species prefer the undersides of leaves, so turn them over when checking for this pest. Also check for evidence of natural enemies such as lady beetles, lacewings, syrphid fly larvae and the mummified skins of parasitized aphids. Look for disease-killed aphids as well: They may appear off-color, bloated or flattened. Substantial numbers of any of these natural control factors can mean that the aphid population may be reduced rapidly without the need for treatment.

FIG 6. Aphid Mummies (light tan) parasitized by *Aphidius colemani. Photo courtesy D. Cappaert, Michigan State University, Bugwood.org #5255047*

Natural Enemies of Aphids

Aphidius colemani

Aphidius colemani works best at a temperature of 50 to 76 degrees F and tolerates cool temperatures. It is not affected by short day length. This tiny, black parasitic wasp attacks the green peach aphid and many closely related species, and eats honeydew, the sticky fluid produced by aphid infestations. It lays its eggs in aphids, and all of the wasp's life stages develop inside the aphid. When the wasp larvae spin cocoons, the aphid's body will swell. The adult wasp then exits the aphid body, leaving behind a hard brown shell called an aphid mummy (Fig. 6). *A. colemani* occurs naturally outdoors and frequently parasitizes aphids in greenhouses. It is a good searcher and can locate new aphid colonies when aphid populations are low.

TABLE 3. EFFECT OF PARASITIC WASPS ON CONTROL OF APHIDS IN UNHEATED GREENHOUSES AND HIGH TUNNELS[1]

CROP[3]	SUCCESS RATING OF APHID CONTROL WITH PARASITIC WASPS[2]		
	Aphidius colemani	*Aphidius ervi*	*Aphelinus abdominalis*
Winter Greens	5 (combination of *A. colemani* and *A. ervi*)		-
Tomatoes in Greenhouse	4 (plus Aphid Stop)	-	-
Eggplants	5 (plus PyGanic®)	-	-
Peppers	4.75 (plus insecticidal soap)	-	-
	5 (combination of *A. colemani* and *A. ervi*)		-
	5 (combination of *A. colemani* and *A. ervi*)		-
Cucumbers in Greenhouse	0 (combination of *A. colemani*, *A. ervi* and *A. abdominalis*)		

[1] 2007 through 2010
[2] Each number represents the success rating of control in one season at one of 19 case studies where 0 = control failed; 3 = pest was controlled; 5 = pest was eradicated.
[3] Crops were produced in high tunnels unless noted otherwise.

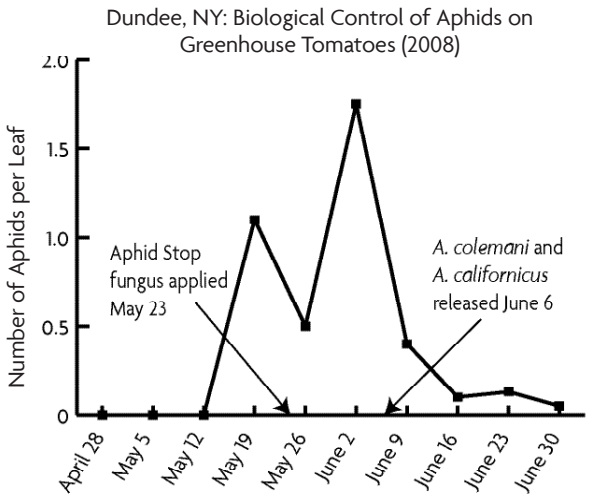

FIG 7. Effect of release of *Aphidius colemani* and *Amblyseius californicus* in combination with Aphid Stop on aphid population on tomatoes in a greenhouse (7).

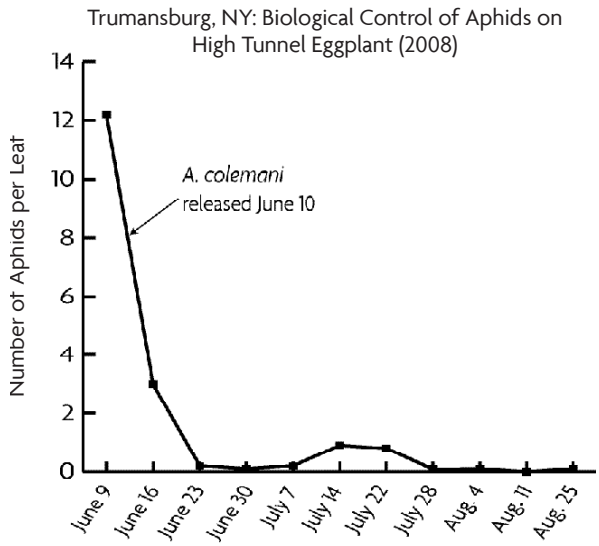

FIG 8. Effect of release of *Aphidius colemani* in combination with PyGanic® on aphid population on eggplant in a high tunnel (8).

Application

Depending on the extent of infestation, release 500 to 3,000 per acre two or three times, with one week between releases. Follow the instructions provided by your distributor, but in general, release *A. colemani* at the first sign of an infestation of aphids. It may be necessary to remove heavily infested plants or to apply a knock-down spray before releasing the parasitic wasp. However, leaves with parasitized aphids should remain in the greenhouse or high tunnel until the next generation of wasps emerge. After releasing, continue to monitor both live and parasitized aphids. Repeat releases of natural enemies as needed.

Aphidius ervi

This small, black wasp parasitizes all types of large aphids. It prefers an air temperature of 86 degrees F.

Application

Release one adult per 20 to 100 square feet for preventive releases, or five times as much for heavy infestations. Follow the instructions provided by your distributor, but in general, release *Aphidius ervi* at the first sign of an infestation of aphids. It may be necessary to remove heavily infested plants or to apply a knock-down spray before releasing the parasitic wasp. If pruning leaves, check for parasitized aphids. Leaves with parasitized aphids should remain in the greenhouse or high tunnel until the next generation of wasps emerge. After releasing, continue to monitor both live and parasitized aphids. Repeat releases of natural enemies as needed.

Combination of Management Tools

Researchers recommend using a combination of the parasitic wasps *A. colemani* and *A. ervi* to control aphids on warm season crops (8, 17, 21) (Table 3). This combination is effective when applied at the first sign of an aphid infestation and when environmental conditions are right. Release more than one species of parasitic wasp in order to cover a wider range of aphid species because each species of wasp parasitizes different aphid species, and waiting to confirm the presence of a particular aphid species is not practical. Researchers experienced two failures using this combination. In one instance, the wasps were released in a high tunnel in a cool fall environment, and in the other they were released in a greenhouse in a winter environment.

Researchers found other successful combinations. For example, aphid parasites in combination with an application of Aphid Stop eradicated aphids on tomatoes in a greenhouse (7) (Fig. 7) and on winter greens (10) and peppers (17, 18) in high tunnels at several locations in 2008. Aphid Stop is a commercial formula that claims to repel aphids.

A combination of the organically compliant, broad-spectrum contact insecticide PyGanic® and the aphid parasite *A. colemani* was also successful, eradicating aphids on eggplant in high tunnels at one location in 2008 (8) (Fig. 8).

The combination of insecticidal soap and one release of the aphid parasites *A. colemani* and *A. ervi* almost eradicated aphids on peppers at one location in 2008 (21). Releases of the aphid parasites *A. colemani*, *A. ervi* and *Aphelinus abdominalis* failed to control aphids on cucumbers grown hydroponically at one location in December 2010 (23).

Management of Whiteflies

Introduction

Several species of whiteflies can be found on vegetable crops and flowering annual plants in the Northeast. Like

aphids, whiteflies suck sap from plants and excrete honeydew. Adults lay eggs on the underside of leaves. The first-stage nymphs crawl on the plant for a short time before becoming immobile scales. The scales are flattened disks, much like one layer of a round cake.

Their feeding may cause stunting, wilting or yellowing of plants, defoliation, reduced yields, and plant death. The sticky honeydew they leave behind on the plant can interfere with photosynthesis. Whiteflies can reproduce rapidly in a favorable environment that is absent of natural enemies.

How to Scout for Whiteflies

Inspect the upper and lower surfaces of plant leaves weekly for adults, eggs and immobile scales. Look for adults near plant tops or the ends of branches. The adults are tiny, white insects with four wings. If you disturb the plant foliage, adults will fly up and be easier to spot. Use a hand lens to identify scales, because they are translucent and difficult to see. You can also use yellow sticky cards (one card per 1,000 square feet) to monitor adults. Place the cards just above the tops of plants and record the number counted once or twice each week.

Adults and eggs are more often found on younger leaves; scales are found on older leaves. Scales are difficult to see because they are translucent unless parasitized. If eggs and scales are found, scout more frequently in order to track the hatching of crawlers from those plants. If you plan to apply an insecticide, remember that the crawler is the only stage that is susceptible to insecticides.

Natural Enemies of Whiteflies

Encarsia formosa

Encarsia formosa is a tiny wasp that attacks greenhouse and silverleaf whiteflies. Adult female *E. formosa* kill whitefly scales in two ways: by puncturing and feeding on scales, or laying their eggs in scales. *E. formosa* eggs hatch into tiny larvae, causing the whitefly pupae to turn black as the young wasps mature. Suppliers ship the parasites inside the blackened whitefly scales, which are attached to cards in batches of 50 to 100 per card.

E. formosa prefers an average temperature above 64 degrees F, and 70 percent relative humidity. Release *E. formosa* at the first sign of whiteflies on yellow sticky cards. Release at one- to two-week intervals for six to eight weeks.

Researchers used *E. formosa* (Nile Delta) to manage whiteflies on tomatoes in high tunnels at one location in 2008 (5) (Table 4). They made only one release of *E. formosa* when whitefly numbers were high. The release managed but did not eradicate whiteflies; the whitefly population began to grow after several weeks and remained high, but the grower felt this pest was sufficiently controlled.

TABLE 4. EFFECT OF *ENCARSIA FORMOSA* ON CONTROL OF WHITEFLIES IN HIGH TUNNELS[1]

CROP	SUCCESS RATING OF WHITEFLY CONTROL WITH *ENCARSIA FORMOSA*[2]
Tomatoes	5; 3

[1] 2007 through 2010
[2] Each number represents the success rating of control in one season at one of 19 case studies where 0 = control failed; 3 = pest was controlled; 5 = pest was eradicated.

Application

Release *E. formosa* preventively at a rate of one card per 6 square feet every two weeks. At the first sign of whiteflies on plants, release one card per 3 square feet. Suppliers may have additional instructions.

Management of Multiple Pests

To manage multiple pests, researchers recommend two approaches: releasing multiple species of natural enemies at one time or releasing multiple natural enemies over the course of the growing season. For heavy infestations of pests, it may be necessary to remove the most infested plants or spray them with an insecticide to knock down the pest population before releasing the natural enemies. When using multiple controls, consult with Cooperative Extension personnel or commercial distributors of natural enemies to make certain the chosen tools work well together. Insecticides vary in their impact on natural enemies; some insecticides are toxic to natural enemies, even in residual form.

SARE Research Summary

In 2007, 2008 and 2009, SARE funded a research project, *Natural Pest Management in New York High Tunnel and Greenhouse Vegetables* (LNE07-262), to study the efficacy of releasing natural enemies to control insect pests on vegetables grown in minimally heated greenhouses and high tunnels. The researchers recruited vegetable growers to host the on-farm trials, conducted a poll to determine their most problematic pests, established randomized research plots on each farm, and monitored pest numbers before and after releasing the natural enemies. In total, this included 23 case studies involving tomatoes, cucumbers, eggplants, winter greens and peppers grown at nine locations in upstate New York. In several case studies, a pesticide was applied in addition to releasing the natural enemy.

The size of the plots, densities of the crop plants and methods of pest monitoring varied by crop, site and year. Researchers monitored pest populations before and after applying the natural enemies by counting the numbers of each pest and/or rating their damage every one to two weeks. In

addition, the overall success of the control method at each case study was rated on a scale of 0 to 5 as failed (0 rating), controlled (3 rating) or eradicated (5 rating). Pest population data was entered into spreadsheets and the mean population density or damage rating was calculated.

Thrips were monitored by counting their numbers on 12 leaves per block. Two-spotted spider mites were monitored by rating their damage to leaves on a scale of 1 (leaves are free of damage) to 10 (leaves are dead). Aphids and whiteflies were monitored by counting their numbers on approximately three to five leaves or leaflets per plant. Further details on scouting procedures are available in the Farm-by-Farm Demonstration Trial Results in Reid, J. 2010b.

Trial data and input from growers indicated that while biological pest control with natural enemies is difficult to quantify economically in field settings, it can be the difference between a crop and a failure, and for many organic growers it is their only option.

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COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF KENTUCKY COLLEGE OF AGRICULTURE, FOOD AND ENVIRONMENT, LEXINGTON, KY 40546

Biological Control of Arthropod Pests in High Tunnels and Greenhouses

John Obrycki, Professor, and Ric Bessin, Extension Specialist

Entfact-327

Production of vegetables in protected environments, high tunnels and greenhouses, is very different than in the field. Many of the pests that we typically need to manage in the field are relatively uncommon, while some species that we rarely need to manage in the field are the key pests in these protected environments that require management. Groups of pests most commonly needing management on vegetables in high tunnels and greenhouses include whiteflies, thrips, aphids, fungus gnats, and mites. Within each of these types of pests there can be one or more species and proper identification is critical to the success of a biological control program.

Producers of tomatoes and vegetables in high tunnel or greenhouse production systems manage several key arthropod pests to maximize their yields and profits. An environmentally and economically sound management system for these pests is based on the following components:

- *Sanitation* – cultural controls which includes screening ventilators and weed control in and around structures. Removal of heavily infested plants if infestations are localized.
- *Biweekly Monitoring* – visual inspection of plants and sticky cards. Try to set aside a specific time of the week for monitoring so that this activity becomes part of your routine. Use a standard method (number of plants sampled in a specific way) so that you can compare pest levels from one date to other weeks or years. Yellow sticky cards should be placed just over the height of the plants and checked weekly. They will need to be replaced when they become covered with debris, typically once every 2 weeks.
- *Recognize developing pest problems early* – including correct identification. Be familiar with the common pests in their various life stages. Most of these are very small, so a hand lens is usually needed. The publication ID-235, IPM Scouting Guide for Common Problems of High Tunnel and Greenhouses Vegetables, can help with pest identification.
- *Release beneficial species* (natural enemies and pollinators) – monitor effects – consult with extension specialists and suppliers. Beneficial species do not act like insecticides and require management.
- *Anticipate pest problems* based on previous crop history and be ready to order beneficial species. Suppliers typically ship beneficial organisms early in the week to avoid weekends.
- *Maintain records* of scouting and management information.

The first step in managing any problem is to first properly identify the problem. Once it has been identified, in this instance an arthropod pest, then management information becomes available through your local extension office or the internet. If you cannot identify the problem, take a sample or good quality image to your local county extension agent. This service is available at no charge for the citizens of Kentucky. Entfact-001, available online, provides advice on taking a sample and a good insect photo. If the county agent is not able to identify the problem, the sample will be sent to UK for identification.

There are insecticides or miticides available for control/suppression of arthropod pests in high tunnels and greenhouses. However, many of the insecticides we can use in the field are prohibited in high tunnels and greenhouses. For purposes of pesticide applications, high tunnels are considered greenhouses. If you use biological control, you must be careful when selecting and using insecticides (miticides) as many insecticides may also kill the beneficial insects and mites. Selective insecticides, such as those containing Bt, are more compatible with biological control.

If a grower plans to use biological control for management of arthropod pests in a high tunnel system, the following items need to be considered in their decision:

Considerations

- Best to begin biological control when pests are at low densities. Will not work if pest numbers are high.
- Requires more management in terms of identification and monitoring of both pest and beneficial activity.
- Will not eliminate pests, but keeps them at very low levels when successful.
- Different pest groups usually require different types of natural enemies to be released.
- Proper identification of pest species is critical.

Advantages

- Reduces insecticide use.

- Self-sustaining in that they reproduce and potentially provide control over an extended period; many of these biological control organisms can fly, so they will distribute themselves within a high tunnel or greenhouse structure.
- If pest problems develop, they buildup more slowly.
- May result in higher profits.
- No human exposure to insecticides, thus there are no requirements for record keeping, personal protective equipment (PPE), restricted entry intervals (REI) or pre-harvest intervals (PHI)

There are several species of biological control organisms that are commercially available, that are highly effective against arthropod pests attacking Kentucky tomato production systems. To be successful using beneficial species, release rates and timing need to be matched with pest populations in your greenhouse. Your county agent or supplier of the beneficial organisms can help you with this. It is also best to avoid releasing beneficial insects during the middle of the day. Either late afternoon or early morning is a better time for release and establishment of natural enemies. When receiving a shipment of natural enemies, always check to see that they arrive in good condition, otherwise call the supplier for a replacement.

One big difference between high tunnels and greenhouses is ventilation. Most high tunnels have passive ventilation through side walls that are opened up while greenhouse have smaller windows and fans to move the air actively. Beneficial insects typically have a winged stage and can disperse easily. High tunnels can be fitted with screens, but care should be taken not to reduce airflow with very fine screens.

Commercially Available Biological Control Organisms

Spider Mites
Two species of predatory mites (*Phytoseiulus persimilis*) and (*Amblyseius fallacis*) have been shown to be very effective for two-spotted spider mites. If your structure has a history of tomato russet mite infestations – release *A. fallacis* predatory mites. The predatory mite (*Amblyseius swirskii*) is an effective predator of broad mites. A small predatory lady beetle species can also be purchased for mite suppression (*Stethorus punctillum*).

Aphids
Predatory lacewings can be released for aphid suppression. Also available is a predatory fly (*Aphidoletes aphidimyza*). A number of species of stingless wasps (aphid parasitoids) are commercially available for several different aphid species. For example, *Aphidius colemani* was released in a Kentucky greenhouse for suppression of melon aphids and provided season long suppression of this aphid pest. Important to know the species of aphid pest to determine the most appropriate species of stingless wasp to release.

Sorghum banker plants have been used to sustain aphid parasitoids in greenhouses as the aphid species attacking sorghum do not attack greenhouse vegetables and the grain aphids on sorghum support the parasitoids.

Fungus Gnats
Cultural controls – avoid over-watering and standing water. Commercially available biological control organisms include entomopathogenic nematodes, predatory mites, and a bacterial insecticide (Gnatrol)

Thrips
At least two species of predatory mites are reared by insectaries and can be purchased for release against thrips - *Neoseiulus* (*Amblyseius*) *cucumeris* and *Amblyseius swirskii*. *Amblyseius swirskii* is also used to control mites.

Whiteflies
Correct identification of the species of whitefly infesting your structure is critical in selecting a biological control organism. At least two species of tiny stingless wasps can be purchased for release against whiteflies – *Encarsia formosa* (greenhouse whitefly) and *Eretmocerus eremicus* (silverleaf or sweetpotato whitefly). A predatory lady beetle (*Delphastus catalinae*) can also be released for whitefly suppression.

Additional Sources of Information:
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Inclusion in the following list of sources of information does not imply any endorsement nor does exclusion imply any criticism of suppliers or their products.

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Rincon Vitova Insectaries http://www.rinconvitova.com/

Released: 10/18

COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF KENTUCKY COLLEGE OF AGRICULTURE, FOOD AND ENVIRONMENT, LEXINGTON, KY 40546

Pesticide Calculations for Small Acreages

Ric Bessin, Extension Specialist

Entfact-800

Most agricultural pesticide labels list use rates on a per acre basis, but this can pose an issue for many producers of specialty crops. Often only a small fraction of an acre needs to be treated and it is important to apply these pesticides at the correct dose. Over application is illegal as it may result in excessive residues on the harvested produce, injury to the plant, and a waste of money. Under application can result in ineffective control, foster the development of resistance, and also a waste of money. So, determining the correct amount for the proper dosage is required. While there are many different methods to do this, this article outlines a simple process that can be used to determine amounts of products needed for small acreages.

Figure 1. Mapping programs like Google Maps can be used to determine the area if irregular-shaped fields.

1. *Determine the area to be treated*

The simplest method is to measure the width and length of the area to be treated and multiply those two numbers together. For example, if the area to be treated is 24 feet by 150 feet, then the area would be 3,600 ft^2.

(1) 24 ft wide x 150 ft long = 3,600 ft^2

There are 43,560 ft^2 in an acre, so in this example, the acreage to be treated would be 3,600 divided by 43,560, or 0.0826 acres.

(2) 3,600 ft^2 / 43,560 ft^2/ acre = 0.0826 acres

While this method works well for rectangular fields, it can be difficult to determine the area of some irregular-shaped fields. On-line mapping programs like Google Maps can calculate the area of irregularly shaped objects. Bring up the field with the mapping program and right click on the edge of the area to treated and select 'measure distance'. Add more points around the perimeter by right clicking on those points until the object is encircled. The area of the object will be provided in square feet. Convert square feet to acres by dividing the number by 43,560 ft^2.

2. *Determine the amount of product needed for the area to be treated*

First decide on the rate per acre based on the label. While this sounds simple and straight forward, just picking the rate listed on the label for the crop to be treated, many labels list a range of rates allowing the use to select a rate within the range. Generally, the low rate is used for small plants and light insect or disease pressure. As the plants get larger or insect and disease pressure increases, higher rates within the range should be selected. However, we cannot apply more than what is listed on the pesticide labelling.

Take the rate per acre you selected in and multiply that by the acreage you calculated in #1. For example, you decide to apply 5.2 fl. oz. per acre (from the pesticide label) and the area to be treated is 0.0826 acres, then the amount of product needed would be 0.43 fl. oz

(3) 5.2 fl. oz. per acre x 0.0826 acres = 0.43 fl. oz.

You would need to put the 0.43 fl. oz. in the correct amount of water and apply it evenly to the area to be treated. But it would be difficult to measure 0.43 fl. oz., so I convert this to milliliters (mls) so I can use a plastic syringe for accuracy. There are 29.6 mls in a fluid ounce, so in our example we would multiply 0.43 by 29.6 to get 12.7 mls.

(4) 0.43 fl. oz. x 29.6 mls/fl. oz. = 12.7 mls

This is the amount of pesticide needed to treat our field and this can be measured easily and accurately with a syringe.

Another way to measure small amounts of fluids is to use teaspoons or tablespoons. A teaspoon is approximately 5 mls and a tablespoon is 15 mls. So, 12.7 mls would be about 2 and a half teaspoons. But keep in mind that these spoons must to be dedicated to only measure pesticides and not used for other purposes.

(5) 12.7 mls / 5 mls per teaspoon = 2.54 teaspoons

3. Determine the amount of water needed

The method I use is to completely fill the sprayer I plan to use with plain water, then spray a known area. The I measure the amount of water needed to refill the sprayer. For example, I measure out an area 3 ft wide by 100 feet in length (300 ft^2). I fill my sprayer and apply water to that area is the same way I plan to apply the pesticide (same speed, pressure, nozzles, etc.). Suppose it took a quart of water to refill the sprayer. To determine the water per acre, take the water need and multiply by 43,560 and divided by the area we treated.

(6) 1 quart x 43,560 ft^2/acre / 300 ft^2 = 145.2 qt/acre

(7) 145.2 qt/acre / 4 quarts per gallon = 36.3 gal/acre

Multiply this by the area to be treated from #1 to determine the amount of water you need to mix with the pesticide. Here we would need 0.0826 acres x 36.3 gallons. The total amount of water needed would be 3 gallons of water.

(8) 0.0826 acres x 36.3 gallons/acre = 3.0 gallons

So, to apply our pesticide in this example, we would put 12.7 mls in 3 gallons of water to treat an area 24 by 150 feet in size. \

Dry Pesticides

We can do the same with dry pesticides, but the conversion from ounces to grams would be 1 ounce equals 28.35 grams. So, let's say we wanted to apply a pesticide in the same field that calls for 3.5 oz. per acre. We start the same as above by multiplying the rate per acre by the acreage to be treated.

(3 dry) 3.5 oz. per acre x 0.0826 acres = 0.29 oz.

I measure small amounts of pesticides with a small electric scale that accurately measures in grams. Since there are 28.35 grams in an ounce, we would need to apply 8.22 grams.

(4 dry) 0.29 oz. x 28.35 grams/oz = 8.22 grams

We would calculate the amount of water needed as we did above with the liquid pesticide example.

Small Acreage Pesticide Calculation Worksheet

1. **Field area to be treated:** [ ] Width in feet x [ ] Length in feet = [ ] Area to be treated ft^2

Or area determined by mapping program [ ] ft^2

Convert to acres: [ ] Area to be treated ft^2 / [43,560] ft^2 per acre = [ ] Acres to be treated acres

2. **Determine the amount of product needed for the area to be treated**:

[ ] Rate per acre from label x [ ] Acres to be treated = [ ] Product needed

3. **Determine the amount of water needed to treat the field:**

Calibration area: [ ] Width in feet x [ ] Length in feet = [ ] Calibration area ft^2

[ ] Water used to cover calibration area X 43,560 ft^2 / [ ] Calibration area = [ ] Water needed to treat 1 acre

(Units used for calibration will be the same units as the units of water needed per acre)

Water to treat field: [ ] Acres to be treated x [ ] Water needed to treat 1 acre = [ ] Water needed to treat field

Above example:

1. **Field area to be treated:** [24] Width in feet x [150] Length in feet = [3,600] Area to be treated ft^2

Convert to acres: [3,600] Area to be treated ft^2 / 43,560 ft^2 per acre = [0.0826] Acres to be treated acres

2. **Determine the amount of product needed for the area to be treated**:

[5.2 fl. oz/acre] Rate per acre from label x [0.0826] Acres to be treated = [0.43 fl. oz.] Product needed

3. **Determine the amount of water needed to treat the field**

Calibration area: [3] Width in feet x [100] Length in feet = [300] Calibration area ft^2

[1 quart] Water used to cover calibration area X 43,560 ft^2 / [300] Calibration area = [145.2 quarts] Water needed to treat 1 acre

Water to treat field: [0.0826] Acres to be treated x [145.2 quarts] Water needed to treat 1 acre = [12.0 quarts] Water needed to treat field

DISEASE MANAGEMENT ROADMAP FOR SMALL ACREAGE GROWERS

Resource 081

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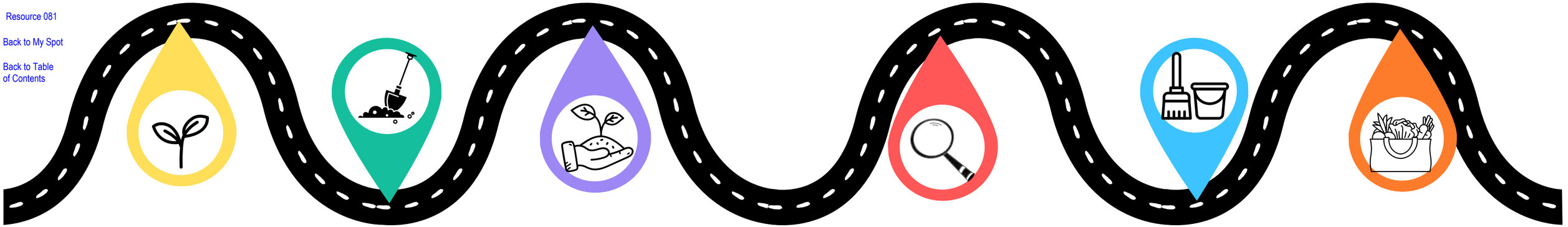

Planning

- Treat saved seed with hot water or chlorine (bleach) to kill disease-causing pathogens.
- Select cultivars with tolerance or resistance to plant diseases.
- Intercrop or succession plant with crops that are not susceptible to the same diseases.

Site Preparation

- Rotate crops from different families for two to three years.
- Fertilize according to soil test results; do not overfertilize.

Planting

- Avoid planting too early; wait until soil and air temperatures are suitable for the crop.
- Space plants to allow for increased air flow and reduced humidity.
- Use mulch to preserve soil moisture and reduce movement of pathogens; cover crops can also serve as a mulch layer.

Identifying Problems

- Scout regularly for abnormal plants or growth patterns.
- Remove dead, dying, and diseased tissue as soon as possible.
- Contact a county Extension agent for disease identification, management recommendations, or assistance submitting samples to the Plant Disease Diagnostic Laboratory.
- Fungicide and biologicals are best used as preventatives, especially when disease was a problem the previous year.

Sanitation

- Avoid tracking soil from infested areas to clean fields.
- Remove infected plant parts throughout the growing season.
- Harvest marketable produce in one container and damaged/diseased produce in another.
- Do NOT compost diseased plants or produce.

End of Season

- Remove all leaves, stems, roots, and produce from fields or structures.
- Clean and sanitize all tools and harvest equipment.
- Save seeds from the best produce.
- Plant a cover crop that provides disease management benefits.

Connect with Plant Pathology Extension @KYPlantDisease @KYPlantDisease @NicoleGauthier

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COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF KENTUCKY COLLEGE OF AGRICULTURE, FOOD AND ENVIRONMENT

Plant Pathology Fact Sheet PPFS-GH-01

Managing Greenhouse & High Tunnel Environments to Reduce Plant Diseases

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Introduction

Greenhouse and high tunnel environments, which tend to be warm and humid, often create ideal situations for disease development. Environments favoring infection and spread of many disease pathogens include one or more of the following: high relative humidity (90% or above), free moisture (e.g., leaf wetness, wet soil), and/or warm temperature. Because diseases can cause extensive damage, their management is essential to production of high quality, marketable products. While challenging, these environments can be managed to simultaneously encourage plant growth and discourage pathogen spread.

Figure 1. Many plant pathogens, (such as *Botrytis*, shown here) are favored by the warm, humid conditions that can develop in greenhouses and high tunnels. Pathogens allowed to multiply on diseased tissues serve as sources of infectious material for further disease spread.

Managing Relative Humidity & Temperature

High relative humidity promotes development of many leaf, flower, and fruit diseases, including powdery mildew and gray mold (Figure 1). Daytime relative humidities of 25% to 70% are often low enough that pathogen infection is inhibited. However, when humidity rises above 90%, especially for long periods, disease incidence can also increase. The following practices help manage humidity and temperature.

FIGURE 2. VENTILATING HIGH TUNNEL (LEFT) AND GREENHOUSE (RIGHT) STRUCTURES IS IMPORTANT TO REDUCING INTERNAL RELATIVE HUMIDITY. HIGH HUMIDITY ENCOURAGES THE DEVELOPMENT OF MANY DISEASES, SUCH AS POWDERY MILDEW AND BOTRYTIS GRAY MOLD.

Air Circulation

Fan-jet or horizontal air flow systems should operate continuously in greenhouses during periods of high humidity, which often occur at night and during rainy days. Exhaust fans, when present, can be used to circulate air in greenhouses and in high tunnels when sides are closed.

Ventilation

Exchange air in greenhouses and high tunnels with fresh outdoor air (FIGURE 2) in order to reduce internal relative humidity.

Heated greenhouses

Most winter evenings are cool enough to raise humidity to 100% and result in considerable condensation in greenhouses. Condensation can be reduced significantly with late afternoon ventilations. Ventilation fans exhaust warm moist air from the greenhouse, replacing it with cooler outdoor air. When this fresh air is heated, it becomes much drier and less favorable for disease development.

High tunnels

Ventilation in high tunnels is manipulated by opening sidewalls, endwalls (FIGURE 2), and/or ridge vents, if applicable. For new construction, choose a site with good air drainage and gentle breezes to facilitate ventilation. Prevailing winds will dictate orientation of a ridge vent.

Plant Spacing

Closely-spaced plants and overlapping canopies can create microclimates different from the rest of the structure. These microclimates are often higher in relative humidity than surrounding air and are typically the first place disease develops. Plants should be adequately spaced to allow for air movement during all stages of development. This facilitates drying of foliage and makes it easier to obtain good spray coverage when fungicides are required. Hanging baskets placed overhead also reduce normal water evaporation and contribute to high humidity in crop canopies. Bushy or suckered ornamentals should have wider spacing, especially if plants are not pruned regularly. On determinate tomatoes, suckers and old leaves (up to first bunch of fruit) should be removed to facilitate air flow.

For specific recommendations on vegetable spacing, see *Vegetable Production Guide for Commercial Growers* (ID-36).

Air Temperatures

Temperatures outside the normal range of growth induce stress on plants, and stressed plants are generally more susceptible to

FIGURE 3. PUDDLING WATER ON GREENHOUSE AND HIGH TUNNEL FLOORS INCREASES RELATIVE HUMIDITY, ENCOURAGES WEEDY GROWTH, AND CAN SERVE AS SOURCES OF PATHOGEN INOCULUM. HOSES LEFT ON THE GROUIND MAY BECOME CONTAMINATED WITH PLANT PATHOGENS.

infection by disease-causing pathogens. Rapid temperature fluctuations in structures should also be avoided to reduce plant stress. Consult literature and production guides (e.g., *Vegetable Production Guide for Commercial Growers*, ID-36) for optimal temperatures for specific greenhouse or high tunnel crops.

Avoid Standing Water

Water that collects or puddles under benches or in walkways (FIGURE 3) increases humidity. Standing water also encourages growth of weeds and volunteer plants, which can harbor plant pathogens. Gravel, concrete, or landscape cloth covering dirt walkways reduces the overwintering (or overseasoning) capability of plant pathogens.

SANITATION

Sanitation practices aid in eliminating sources of infectious plant pathogens and minimizing their spread. For more information on this topic, refer to *Greenhouse Sanitation* (PPFS-GH-04).

The following practices can help reduce active and dormant pathogen inoculum levels.

Surface Sterilize Benches, Pots, & Tools

Disease-causing pathogens are often spread through used pots, dirty tools and work surfaces, unswept floors, contaminated hoses (FIGURE 3), and even on human hands and clothing. Avoid any introduction of natural soil from dirty boots. Surface sterilize all work benches and tools regularly to prevent spread of pathogen inoculum. A dilute solution of household bleach (9 parts water to 1 part bleach) or commercial disinfectant will eliminate most pathogens. If using landscape cloth, thoroughly sweep it between cropping seasons and clean by spraying with high pressure water. Landscape cloth should be replaced as soon as it begins to wear. Plastic liners in float beds should be replaced each year.

Clean Up Plant Debris

Most plant diseases cannot be cured, so it may be necessary to discard diseased plant material. Bedding plants and vegetables with root rots, vascular wilts, and viruses should be removed immediately after a positive diagnosis. This prevents pathogen spread to neighboring healthy plants. Diseased parts of woody plants, such as cankers, may be pruned. Plants with a few foliar leaf spots or powdery mildews may be salvaged if diseased material is removed and plants are treated; however, any leaf removal on vegetables should be conservative in order to maintain production levels.

Diseased plant material and debris should be bagged and discarded (trashed or burned) as soon as possible; do not compost. Tobacco mowing should be completed with a sharp blade to minimize plant injury, and then clippings should be removed and discarded; do not dispose of clippings directly outside the greenhouse. Develop a regular schedule to clean-up plant debris on and under benches, in ground beds, and on walkways. Immediate debris removal is important because fungal pathogens can readily produce and disseminate spores on these materials.

Manage Weeds

Remove and discard weeds and volunteer plants inside and outside of growing structures. Excessive weeds outside greenhouses reduce airflow through vents, thus increasing relative humidity in these structures. Weeds in ground beds can increase canopy density and result in higher relative humidity. Additionally, weeds may harbor pathogens and insects that can transmit disease to greenhouse and high tunnel crops; insect-vectored viruses are a particular concern. Gravel or landscape cloth may be used to create a weed-free zone 5 to 10 feet around the outside of structures; herbicides should be used with caution.

Wash Hands Thoroughly After Using Tobacco Products

Tobacco mosaic virus (TMV) is a physically hardy virus particle that can persist on hands after greenhouse workers use cigarettes and other tobacco products. To prevent introduction of this virus to commercially grown crops, workers should wash their hands thoroughly with soap and water after using tobacco products.

Do Not Bring in Soil from Outdoors

Natural soil can harbor many soilborne pathogens that may become serious problems if introduced into greenhouses; non-sterile natural soil should not be allowed into these structures. Sterilize any natural soil used in growing mixes or use a commercial soilless medium. Do not reuse potting media. Remove mud from boots and use foot baths (Figure 4) to prevent tracking natural soil.

Water Management

Many pathogens require free water to infect and reproduce. Wet plant surfaces are often at risk for foliar or fruit diseases, and overly-wet growing media favors development of damping-off and root rot diseases. Additionally, many pathogens are spread from plant to plant by splashing water or flooded soil. The following practices will aid in management of moisture in greenhouse and high tunnel systems.

Avoid Wetting Foliage

Whenever possible, opt for drip irrigation instead of overhead irrigation; this keeps plant surfaces dry. If using overhead irrigation, water early so foliage dries by midday.

Water Only As Needed

Monitor plants closely and water judiciously, but only as needed. Variations in light levels, temperature, and humidity affect plant requirements for water. For example, plants require less water during periods of cloudy weather. In addition, plants arranged beneath overhead hanging baskets (Figure 5) do not dry as quickly as those exposed to bright light or full sun. Plants with similar water requirements should be grouped together to maximize irrigation efficiency.

Test Water to Ensure Fungicide Efficacy

Water used for tank-mixing or injecting fungicides should be tested for pH and alkalinity for maximum fungicide efficacy, as well as maintenance of application equipment. For more information on water quality, see *Understanding Irrigation Water Test Results and Their Implications on Nursery and Greenhouse Crop Management* (HO-111) and *Fungicide Tank-Mixes and Incompatibilities* listed in Additional Resources.

Figure 4. Use foot baths to prevent tracking natural soil (and potential pathogens) into greenhouses.

Figure 5. Monitor plant water needs and irrigate accordingly. Variations in growing conditions affect plant water requirements. For example, plants produced under hanging baskets may not need to be watered as frequently as those exposed to more direct sunlight.

Soil Management

Soilless Growing Media

Commercially prepared soilless media are usually free of plant pathogens and are recommended for commercial production in flats and pots. To avoid contamination, bags of media should be stored where they will not become excessively wet or have direct contact with natural soil.

Ground Beds (Natural Soil)

Growers should invest effort into maintaining pathogen-free soils in ground beds by following the recommendations below.

Crop and soil bed rotation

Rotate crops and soil beds to plants that are non-hosts of prevalent diseases in order to prevent buildup of populations of soilborne plant pathogens. Moveable high tunnels on rails allow alternation of the cropping site, which can reduce soilborne pathogens through natural weathering, fallow periods, or by using a non-host cover crop.

Salt buildup

Salt buildup in soils that are intensively cropped can stress plants and predispose them to disease. Monitor nutrient and salt levels with regular soil testing and follow nutrient recommendations. For more information on nutrient management, see *Vegetable Production Guide for Commercial Growers* (ID-36).

Fumigation

Fumigation is broadly effective in reducing a number of soilborne pathogens (e.g., root knot nematode, *Fusarium*, and *Verticillium*), but can also reduce populations of beneficial soil microorganisms. Only applicators with specialized Category 1b licenses may utilize fumigants. As of the date of this publication, grower access to commercial fumigators in Kentucky is limited and costly.

Non-fumigant products

Non-fumigant products have more specific modes of action against soilborne plant pathogens, and their efficacy relies on accurate disease

diagnosis. These products are usually applied to soils via drip irrigation systems. Non-fumigants suppress disease rather than broadly eliminate soilborne pathogens, so regular applications are necessary to realize yield benefits. These are most effective when combined with resistant or tolerant varieties. For specific non-fumigant options for vegetables, see *Vegetable Production Guide for Commercial Growers* (ID-36).

Soil solarization

Soil solarization is another broadly effective approach used to reduce soilborne plant pathogen levels. For more information about soil solarization, see *Soil Sterilization for High Tunnels* (Hort Fact-7003).

Additional Resources

- Greenhouse Crop Diseases and Disorders (Plant Pathology Extension Publications)
http://www2.ca.uky.edu/agcollege/plantpathology/extension/pubs.html#GreenD
- Herbaceous Ornamental Diseases and Disorders (Plant Pathology Extension Publications)
http://www2.ca.uky.edu/agcollege/plantpathology/extension/pubs.html#OrnamentalHerbaceous
- Burley and Dark Tobacco Production Guide (ID-160)
http://www2.ca.uky.edu/agc/pubs/id/id160/id160.pdf
- Foot Baths for Animal Facilities: Easier Than You Think! (University of California Division of Agriculture and Natural Resources)
Note: While this publication was written for animal facilities, the foot bath design it describes could also be used in greenhouses.
http://anrcatalog.ucanr.edu/pdf/8281.pdf
- Fungicide Tank-Mixes and Incompatibilities
http://nicolewarduk.blogspot.com/2014/04/fungicide-tank-mixes-and.html
- Greenhouse Sanitation (PPFS-GH-04)
http://www2.ca.uky.edu/agcollege/plantpathology/ext_files/PPFShtml/PPFS-GH-4.pdf
- High Tunnel Crop Profiles (Center for Crop Diversification)
http://www.uky.edu/ccd/production/system-resources/gh-ht
- High Tunnel Webinar Series (Center for Crop Diversification)
http://www.uky.edu/ccd/training/webinars/ht
- Soil Sterilization for High Tunnels (Hort Fact-7003)
https://www.uky.edu/Ag/CCD/HortFact7003.pdf
- Understanding Irrigation Water Test Results and Their Implications on Nursery and Greenhouse Crop Management (Hort-111)
http://www2.ca.uky.edu/agc/pubs/HO/HO111/HO111.pdf
- Vegetable Production Guide for Commercial Growers (ID-36)
http://www2.ca.uky.edu/agc/pubs/id/id36/id36.html

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Photos—Emily Pfeufer (1), Cheryl Kaiser (2, left), Nicole Ward Gauthier (2, right), Steve Berberich (3), and Matt Barton (5), University of Kentucky; and Swen Halverson, Halverson Greenhouses, Jackson County, Kentucky (4)

Revised from the original fact sheet, *Managing the Greenhouse Environment to Control Plant Diseases*, by Brian Eshenauer and Robert Anderson

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Martin-Gatton
College of Agriculture, Food and Environment
Cooperative Extension Service

Plant Pathology Fact Sheet **PPFS-GEN-17**

Cleaning & Disinfecting Hand Tools & Planting Supplies

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Importance

Dirty tools, containers, and surfaces come as no surprise to small commercial growers and residential growers (Figure 1). Rinsing with water to remove obvious soil or plant residues is a common practice. However, this type of basic cleaning can fail to remove microscopic plant pathogens that can remain on surfaces. Tools, containers, shoes, and surfaces should also be disinfected to remove fungal, bacterial, and viral plant pathogens to prevent transmission to healthy plants. Some readily available products can either clean items or disinfect, while others can both clean and disinfect. The following details the cleaning and disinfecting methods suggested for growers with small acreages and residential gardeners. [Note: Guidelines for cleaning and disinfecting surfaces and equipment in large commercial production settings are more stringent; producers should consult *Cleaning and Sanitizing Commercial Greenhouse Surfaces* (PPFS-GH-07) for recommendations.]

Figure 1. Pots (**A**) and trowels (**B**) often become covered with soil; pruners (**C**) may become covered in plant sap or plant debris during use. These items should be cleaned and sanitized to remove potential pathogens.

Products for Cleaning

Cleaning products, such as soaps and detergents, help remove loose organic matter. This partial list includes some of the common products suitable for cleaning. When cleaning tools and supplies, it is helpful to use brushes, scrubbing pads, and paper towels to aid in the removal of dirt and plant debris.

- Dish detergent
- Liquid soap, hand soap
- Household cleaner
- Bathroom cleaner
- Brush or broom
- Towels

Figure 2. Examples of some commonly available products that can be used for cleaning hand tools and supplies.

Products for Disinfection

Disinfectants/sanitizers are products that have anti-microbial activity and can kill disease-causing microorganisms. Microscopic organisms can be transmitted on tools and surfaces, even after rinsing or washing. Disinfectant products may also be labeled as antimicrobials or sanitizers. This partial list is a sample of commonly available products that can be used to disinfect hand tools and surfaces.

Figure 3. Examples of some commonly available products that can be used for disinfecting hand tools and supplies.

Products that can be used to both clean and disinfect are noted with an asterisk (*).

- Rubbing alcohol or alcohol prep pads (available as 70% solution, do not dilute)
- Bleach (Mix 9 parts water with 1 part bleach to produce a 10% solution)
- Trisodium phosphate, TSP (Mix 9 parts water with 1 part TSP powder to produce a 10% solution)
- Hand sanitizer
- Household cleaner, such as Lysol™ Concentrate Disinfectant*
- Antimicrobial bathroom cleaner, such as Scrubbing Bubbles™*

Procedure for Cleaning & Disinfecting

Step 1: Cleaning

Clean and scrub to remove organic matter, which can inhibit the disinfection process. Begin with a water rinse and then follow up with a soapy wash. Rinse surfaces after washing to remove residues.

Figure 4. Brushes are helpful for scrubbing soil and debris from hand tools, such as pruners and trowels.

Step 2: Disinfecting

Methods for disinfection include soaking (Figure 5A), dipping (Figure 5B), and spraying (Figure 5C). Exposure time is the length of time the product needs to remain in contact with the surface to kill or inactivate pathogens. Most products, including household cleaners (Lysol™), rubbing alcohol (70%) and TSP (10%) require a 3- to 5-minute soak to effectively sanitize (inactivate pathogens). Note that bleach is the most effective disinfectant and can kill surface microorganisms within 30 seconds.

Both bleach and TSP are corrosive to metal tools and can be harmful if inhaled; thus, they are not recommended as a first choice for disinfection. Never mix bleach with other cleaning products, as a toxic gas can be produced. Hand tools with wooden parts are often more difficult to disinfect than those made of plastic, metal, or fiberglass.

Figure 5. Supplies, such as pots, can be soaked in a disinfectant solution (**A**). Pruners, scissors, and trowels can be dipped in disinfectant; be sure entire cutting surfaces are completely submerged in the solution (**B**). Some disinfectant products can be applied by spraying (**C**).

Step 3: Rinse & Dry

A thorough rinse (Figure 6) can remove residues, as well as products such as bleach, that may corrode tools and metal surfaces. Allow tools to dry completely before storing (Figure 7). Some tools may benefit from oiling before storage.

Figure 6. Tools, pots, and other supplies should be rinsed with clean water after disinfecting. **Figure 7.** Pots and tools should be completely dry before storing. While pots can be set out to air-dry, metal tools should be dried completely with paper towels to prevent rust.

Additional Resources

- Cleaning and Sanitizing Commercial Greenhouse Surfaces (PPFS-GH-07) https://plantpathology.ca.uky.edu/files/ppfs-GH-07.pdf
- Fruit, Orchard, and Vineyard Sanitation (PPFS-GEN-05) https://plantpathology.ca.uky.edu/files/ppfs-gen-05.pdf
- Greenhouse Sanitation (PPFS-GH-04) - https://plantpathology.ca.uky.edu/files/ppfs-gh-04.pdf
- Landscape Sanitation (PPFS-GEN-04) https://plantpathology.ca.uky.edu/files/ppfs-gen-04.pdf

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Disclaimer

Other products not listed in this publication may be appropriate and provide adequate cleaning and/or disinfection. Inclusion in this document does not confer endorsement of the product or brand.

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Photos: University of Kentucky - Kimberly Leonberger (Figures 1 to 5, 7) and Cheryl Kaiser (Figure 6)

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College of Agriculture, Food and Environment
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Plant Pathology Fact Sheet

PPFS-VG-28
CCD-FS-22

Root-knot Nematode
in Vegetable Cropping Systems

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Importance

Root-knot nematodes (*Meloidogyne* spp.) are plant-parasitic roundworms that result in decreased plant vigor and yield, followed by eventual plant death. These microscopic organisms reside in soil and infect plant roots. Root-knot nematodes are the most detrimental plant-parasitic nematode to vegetable crops. If unmanaged, populations of root knot nematode (RKN) increase each year. Severe infestations may result in death of crops and significant economic loss for growers.

Host Range

Root-knot nematodes have wide host ranges that include over 500 plant species. They are known to infect many species of ornamentals, fruits, and vegetables. Most vegetables, including tomato and potato, are susceptible to RKN. A large number of weed species are also susceptible.

Symptoms

Aboveground

Aboveground symptoms result from damage to the root system. Infection of roots by RKN limits the ability of plants to take up water and nutrients from soil. As a result, plants exhibit stunting, wilting, and dieback. More severe aboveground symptoms likely indicate a heavily infected root system. Plants may appear stunted with leaves becoming chlorotic (yellow) and eventually necrotic (brown) (Figure 1). Wilting may occur during periods with high temperatures or dry conditions. Infected plants may also have delayed maturity and lower yields compared to healthy plants.

Figure 1: Plants infected by root-knot nematode may appear stunted with chlorotic leaves, which eventually become necrotic.
Figure 2: Roots infected with RKN develop galls or swollen areas.

Symptomatic plants may first be localized, later expanding to a larger area. It is also common for there to be multiple "hot spots" with high RKN populations within the same field, high tunnel, or garden. Over time, entire plantings can become infected.

Figure 3. The skin of tubers infected with RKN may have a bumpy appearance.

Root Symptoms

Roots infected by RKN develop swollen areas or "knots", known as galls (Figure 2). Severely infected roots may have numerous galls, which fuse together and give roots a distorted appearance. Galls vary in size and shape depending on RKN species, population density, and host crop. It is important to note that different crops develop different symptoms when infected with RKN. Crops such as carrots may develop lateral roots, giving them a hairy look. Sweet potatoes and potato tubers may appear to have bumpy, swollen areas on the surface (Figure 3).

Cause, Nematode Life Cycle & Infection

The most common RKN species in Kentucky are northern root-knot nematode (*Meloidogyne hapla*) and southern root-knot nematode (*Meloidogyne incognita*).

Females can produce up to 1,000 eggs. Eggs may stay inside roots or may end up in soil (Figure 4). Under favorable conditions, eggs can survive in soil for up to a year. All nematodes (plant-parasitic or otherwise) have four juvenile stages (J1 through J4). J1 remain inside the egg (Figure 4). J2 hatch from eggs and travel to infect plant roots (Figure 5); this is the only infective stage. Once they have entered a root as juveniles, most RKN females remain in the root throughout their lives, where they feed and reproduce; they are sedentary endoparasites. Nematodes progress through J3 and J4 stages to adulthood. Occasionally, juvenile RKN become males instead of females and exit the root, where they are non-feeding, mate, and die. Females are globular-shape (Figure 6) while males are vermiform (worm-like) (Figure 7). Enzymes secreted during feeding of RKN induce swelling of plant cells into what are called giant cells. Root galling is an outcome of RKN parasitism and can be observed on plant roots.

Root-knot nematodes are capable of completing multiple life cycles in a single growing season. The number of life cycles and the rate at which the population increases depends on numerous factors, such as soil temperature, soil type, and host susceptibility. Soil temperatures between 65°F and 80°F favor faster life cycle completion. Sandy soil is more conducive, whereas heavy clay may discourage reproduction. Root-knot nematode can complete one life cycle in as little as 25 days under optimal conditions (sandy soil at 81°F).

While RKN can move short distances (typically a few inches) through soil to infect new plants, larger scale movement occurs through movement of infested soil by humans. Transplants, as well as boots, tools, and equipment carrying infested soil are capable of moving nematodes longer distances.

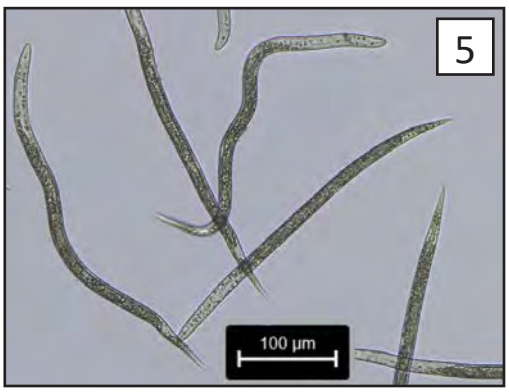

Figure 4: Root knot nematode eggs. The first-stage juvenile (J1) stage is indicated by the black arrow.
Figure 5: Second-stage juvenile (J2) nematodes are motile and begin infection of plant roots.

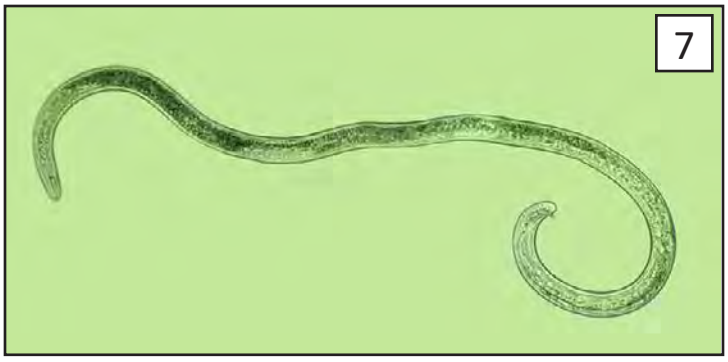

Figure 6: Adult female RKN have a globular form and protrude from roots.
Figure 7: Adult male RKN have a worm-like appearance.

Nematode Testing

Assessing the severity of a field infestation is determined by extracting RKN from soil and plant roots. Many commercial labs offer this service. The number of RKN extracted from soil and roots will determine the level of risk or infection for a particular site or planting. For root infections, more than 1 RKN per gram of root is considered high risk and would require a management strategy. For soil, more than 20 RKN per 100 cc of soil is considered high. Contact a county Extension agent for more information on RKN identification and diagnosis.

Management

Commercial Options (Field & High Tunnel)

Crop Rotation & Plant Selection

Rotating with a non-host or resistant crop is the most effective method for reducing RKN populations. Although RKN has a wide host range, there are resistant or non-host vegetable cultivars (Table 1) that can be used in crop rotations alone or in combination. In order to break the cycle of RKN, host plants (crops, cover crops, and weeds) must be eliminated for at least 2 to 3 consecutive years to provide reliable control of RKN.

Non-host crop species that RKN do not infect or feed on lead to reduced reproduction and an eventual reduction in the overall RKN population. Asparagus, sweet corn, onions, and garlic are non-hosts for RKN, with some exceptions. Many grains, including sorghum, are also non-hosts. Cover crops such as sunn hemp, partridge pea, and cereal rye are non-hosts for RKN, as well as various cultivars of cowpea. These non-hosts, alone or in combination, can be used in a rotation to help break the RKN life cycle.

Some non-hosts are also nematode-suppressive. Nematode-suppressive crops include certain types of marigolds, chrysanthemums, castor bean, partridge pea, velvet bean, vetch, rapeseed (canola), white or yellow mustard, and sesame.

The resistance and host status of some crops can vary among cultivars. Refer to cultivar descriptions when selecting vegetables for crop rotation. Some RKN-resistant cultivars of snap bean, lima bean, sweet potato, English pea, southern pea, broccoli, and tomato are commercially available and can be incorporated into a rotational system. It is important to know which species of RKN is present, as genetic resistance is typically targeted only toward the southern root-knot nematode (*M. incognita*) and may have no impact on the northern root-knot nematode (*M. hapla*). Resistance may be broken if soil temperatures are high.

Resistant rootstocks are another option for introducing resistance into crop rotations. There are many cultivars of tomato rootstock that are resistant to RKN. Tomato cultivars grafted onto resistant rootstocks are available from some transplant producers and can be a viable option for sites with heavy RKN infestations. In trials performed in Kentucky high tunnels, certain rootstocks performed well and were not affected by RKN. Rootstock resistance to RKN may also be broken if soil temperatures are high.

Understanding Host Susceptibility & Resistance Terms

Susceptible crops allow for high levels of nematode infection and reproduction; this makes them a host. The development and yield of susceptible crops will suffer when infected by RKN.

Non-host crop indicates that plant-parasitic nematodes are unable to infect the crop and therefore are unable to reproduce in the presence of that crop. With little to no reproduction occurring, the population of RKN will decrease significantly over time

Suppressive non-host crops reduce nematode populations in soil by depriving them of food and by releasing chemicals that inhibit RKN reproduction and development. Rotating with these plants can provide an effective, non-chemical strategy for managing RKN.

Resistant crops are not absolute non-hosts. They may be infected by plant-parasitic nematodes at reduced levels, and reproduction of those nematodes is reduced. There is a spectrum of resistance—complete resistance (which may also be considered a non-host) to moderately resistant (which may also be considered tolerant). Moderately resistant crops do not completely break the RKN life cycle because they allow nematodes to reproduce, although at significantly reduced levels. Even when moderately resistant/tolerant plants are infected with RKN, they can grow, develop, and produce commercial-level yields.

Weed Management

Many weed species serve as hosts for RKN. It is important to keep plantings free of weeds or volunteer plants, as they may be hosts for RKN and thereby nullify the effect of rotation. Weeds such as amaranth/pigweed, dandelion, and morning glory are hosts for RKN.

Early Planting

RKN reproduction is in part determined by soil temperatures. When soil temperatures are cool (lower than 65°F), RKN reproduction rates are slow to zero. Some susceptible vegetable crops such as radish, lettuce, and spinach can be successfully grown in infested sites because they are grown under cool conditions when RKN is inactive and harvested before soil temperatures increase and RKN can cause significant damage.

Sanitation

Dirty equipment carrying RKN-infested soil is a common way to spread RKN and to introduce RKN into a new field or on-farm location. All tools and equipment should be thoroughly and regularly washed to remove soil particles. Sanitize all pots, benches, and tools before reuse.

If a grower is aware of RKN infestation in one field, they should work in their non-infested or "clean" fields first and then the infested or "dirty" field last. After working in infested fields, tools and equipment should be washed and disinfected. If borrowing equipment, clean completely before using.

Infected transplants and tubers can also introduce RKN into fields and high tunnels. Inspect transplants carefully before planting into fields and high tunnels. If purchasing plant material, be sure to purchase from a reputable source. Infected stock should never be used for propagation.

Chemicals

Fumigation of soil can be used as a management tool in commercial field plantings. However, fumigation is uncommon as a result of cost, regulations, and limited number of commercial applicators who provide the service to small growers. These fumigants, when properly applied, significantly reduce the nematode population, but studies have shown that the effect is temporary. Nematode populations will return to damaging levels within a season in sites replanted to a susceptible crop. Soil fumigants are dangerous to people and animals and should be used with extreme caution. Fumigation is not permitted for use in high tunnels in Kentucky.

Non-fumigant nematicides are labeled for commercial use and can be applied pre- and post-planting for suppression of RKN. These products do not provide absolute control of RKN and should be combined with other cultural control methods. All non-fumigant nematicides, like the fumigants, are dangerous chemicals and should be used with caution. Refer to the "Non-Fumigant Nematicides" table in the *Vegetable Production Guide for Commercial Growers* (ID-36) for a list of registered products.

Biological Control

Products based on microbes or plant extracts are marketed for use in suppressing RKN and other nematodes. Refer to "Biopesticides for Vegetable Disease Management" table in the *Vegetable Production Guide for Commercial Growers* (ID-36) for the most recent list of labeled biocontrol products. In general, biological nematicides provide low to moderate levels of control and are not as effective as conventional nematicides. Biological products can be combined with other cultural practices, such as crop rotation and solarization, for more effective control.

Solarization

The process of trapping the sun's energy to heat soil and inactivate weed seed, pathogens, and pests (including plant-parasitic nematodes) is called solarization. Solarizing soil involves covering an area with clear plastic during the sunniest part of the year and raising soil temperatures to levels that are unfavorable for pathogens and pests. Soil moisture is an important factor in solarization because it helps transfer heat to the target organisms.

Although generally more effective against soil fungi than nematodes, solarization may be an effective strategy to reduce nematode populations without chemicals. Solarization is normally performed for weeks or months at a time. The efficacy is dependent on both time and temperature. In laboratory studies, RKN was killed after 1 hour at 115°F, but accumulation of heat (hours) at temperatures above 100°F was shown to be effective at significantly reducing populations. While high soil temperatures may be difficult to reach in Kentucky, 1 to 4 weeks of solarization conditions should be effective at reducing RKN populations to manageable levels. The time of year, daily temperatures, and hours of sunlight determine the length of solarization needed. Research is ongoing.

Management

Home Garden Options

Crop Rotation

Home gardeners should rotate vegetables from the same crop families to different areas of the garden each year. A rotation schedule that keeps related crops out of the same location for 2 to 3 years is ideal. This management option is most practical in larger garden plots that have more space to rotate crops. Susceptible crops can also be rotated annually with non-host crops such as asparagus, strawberry, or cover crops in order to reduce populations. Including plants such as chrysanthemums, marigolds, or castor beans can suppress RKN development and reproduction. Home gardeners should try to relocate their garden and sow a non-host crop in its previous location when RKN populations are confirmed.

Resistant Varieties

Resistant cultivars of beans, peas, sweet potatoes, and tomatoes are available. Check seed packets or plant labels for information on cultivar resistance.

Early Planting

Early season crops, such as leafy greens and cole (cruciferous) crops, can be planted when soil temperatures are lower and RKN populations are less active. These crops can be harvested before RKN reproduction increases during warmer months.

Sanitation

Home gardeners should inspect transplants and seed pieces prior to planting to ensure that they are not infected with RKN. Regularly clean tools, shoes, pots, and equipment to remove any soil. Infected plants should be removed as soon as possible by digging out the roots and surrounding soil.

Chemical Management

Products for chemical management of nematodes are not available to homeowners.

Additional Resources

- Cleaning & Disinfecting Home Garden Tools & Equipment (PPFS-GEN-17)
https://plantpathology.ca.uky.edu/files/ppfs-gen-17.pdf
- Cleaning & Sanitizing Commercial Greenhouse Surfaces (PPFS-GH-07)
https://plantpathology.ca.uky.edu/files/ppfs-gh-07.pdf
- Home Vegetable Gardening (ID-128)
http://www.ca.uky.edu/agc/pubs/id/id128/id128.pdf
- Soil Solarization for High Tunnels (HORT-7003)
https://www.uky.edu/hort/sites/www.uky.edu.hort/files/documents/solarization.pdf
- Vegetable Production Guide for Commercial Growers (ID-36)
http://www.ca.uky.edu/agc/pubs/id/id36/id36.pdf
- Nematode Suppressive Crops (ANR-856; Alabama Cooperative Extension System)
https://ssl.acesag.auburn.edu/pubs/docs/A/ANR-0856/ANR-0856-archive.pdf
- Soil Fumigant Regulations (University of Georgia)
https://vegetables.caes.uga.edu/external-resources/soil-fumigant-regulations.html

Table 1. Commercially available crop cultivars and their root-knot nematode (RKN) host status.

	Crop	Species	Cultivars		
			Non-Host[1]	Resistant[2]	Susceptible[3]
Vegetable	**Asparagus**	*Asparagus officinalis*		▪ Atlas ▪ Mary Washington	▪ DePaoli ▪ UC157 F2
	Broccoli	*Brassica oleracea*	▪ Arcadia ▪ Decicco ▪ Liberty	▪ Bonanza	▪ Green Magic
	Carrots	*Daucus carota*		▪ Chun Hong (moderately resistant) ▪ Red Cored Chatney	▪ Amsterdam Minicor ▪ Half-Long Nantes
	Cucumbers	*Cucumis sativus*		▪ Dynasty ▪ Long Green Improved ▪ Marketmore	▪ Dasher II ▪ National Pickling ▪ Poinsett 76
	Eggplant	*Solanum melongena*		*Rootstocks:* ▪ Salutamu ▪ Torpedo	▪ Black beauty ▪ Long green ▪ Round Purple
	Lettuce	*Lactuca sativa*			▪ Ithaca ▪ Penn Lake ▪ V155 ▪ V160
	Onion	*Allium cepa*		▪ Mercury	▪ Cape Flat ▪ Tioga ▪ Vision
	Snap Bean	*Phaseolus vulgaris*		▪ Alabama No. 1 ▪ Kentucky Wonder ▪ Manoa Wonder ▪ Mezcla	▪ Harvester ▪ Rico-23 ▪ Rustproof Golden ▪ Wax
	Spinach	*Spinacia oleracea*		▪ America	▪ America Riccio ▪ Bejo 2592 ▪ Dash ▪ New Zealand ▪ Polka
	Sweet Corn	*Zea mays*		▪ Seneca 110 ▪ Seneca Explorer ▪ Sweet Tooth	▪ Merit ▪ Spancross
	Sweetpotato	*Ipomoea batatas*		▪ Bienville ▪ Bophelo ▪ Evangeline ▪ Murasaki ▪ Okinawa	▪ Centennial ▪ Jewel ▪ Norin-1 ▪ Porto Rico
	Tomato	*Solanum lycopersicum*		▪ Atkinson ▪ Beefmaster ▪ Better Boy ▪ Healani ▪ Nematex ▪ Rossol *Rootstocks:* ▪ Arnold ▪ Estamino ▪ Maxifort	▪ Beefsteak ▪ Money Maker ▪ Roma ▪ Rutgers ▪ Santa Cruz
	Zucchini	*Cucurbita pepo*		*Genotypes* : ▪ Alpha Prime ▪ Patio	▪ Amalthee

Table 1. Commercially available cultivars and their root-knot nematode (RKN) host status (cont'd).

	Crop	Species	Cultivars		
			Non-Host[1]	Resistant[2]	Susceptible[3]
Cover Crops	**Cowpea**	*Vigna unguiculata*	▪ Zippercream	▪ California Blackeye 5 ▪ Colossus ▪ Iron Clay ▪ Mississippi Silver	▪ Chinese Red ▪ UCR779
	Mustard, White	*Sinapis alba*	▪ Abraham	▪ Achilles ▪ Condor ▪ IdaGold	▪ Metex
	Mustard, Brown or Yellow	*Brassica juncea*			▪ Caliente 199 ▪ Nemfix ▪ Pacific Gold
	Oat	*Avena sativa*	▪ Coker 716	▪ IPR Afrodite	▪ Brooks ▪ Coker 820 ▪ Sniper
	Oilseed Radish	*Raphanus sativus*	▪ Boss ▪ Defender ▪ TerraNova	▪ Adagio ▪ Chinese Daikon ▪ Colonel ▪ Comet ▪ Sodbuster	▪ Adios ▪ Daikon-Long
	Red Clover	*Trifolium pratense*		▪ Barduro ▪ Krynia ▪ Southern Belle	▪ Cherokee
	Sorghum	*Sorghum halepense*	▪ SX-17	▪ Cherokee ▪ Northrup King 2660 ▪ Pioneer 8333 ▪ Terral RV 9823	▪ BMR Sweet ▪ DeKalb FS25E ▪ DinaGro GX13662
	Sunn Hemp	*Crotalaria juncea*		▪ K-12 Yellow ▪ Tropic Sun	▪ AU Golden
	Wheat	*Triticum aestivum*		▪ Anza ▪ Lassik *Genotype:* ▪ Rkn3	▪ Nugaines

[1] **Non-host**: RKN is unable to infect or reproduce inside the roots; immune to RKN.
[2] **Resistant**: RKN infection is limited and reproduction is suppressed. Moderate resistance indicates that RKN reproduction is reduced, but not completely.
[3] **Susceptible**: RKN can infect the crop and there is a high level of RKN reproduction.

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Plant Pathology Fact Sheet **PPFS-VG-31**

Commercial Spray Schedule for High Tunnel Production of Tomatoes

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Introduction

High tunnel tomato production allows growers to plant earlier in spring or later in autumn, resulting in fruit available for sale before field tomatoes can be marketed. However, numerous plant pathogens can infect tomatoes resulting in plant and/or fruit loss. Applications of fungicides and bactericides are often necessary to limit the impact from plant diseases. Fungicides and bactericides provide the greatest efficacy when applied preventively (prior to disease onset). Growers should develop a spray schedule for each season in order to limit the impact of the various fungi and bacteria that can affect tomatoes. This document provides information on the timing of the most common high tunnel tomato diseases, as well as example spray schedules for conventional and organic systems. Fungicides recommended here include a few of the most common products; a complete list of registered fungicides can be found in *Vegetable Production Guide for Commercial Growers* (ID-36) and *Southeast U.S. Vegetable Crop Handbook* (SEVEW); generic products may also be available. High tunnels are considered greenhouses; use only products that are labeled for greenhouse application.

Timeline of common and important diseases occurring on tomato crops in high tunnel production.

Disease	Time Period
Gray mold	Apr – Aug
Pythium root rot	Apr – Aug
Timber rot	Apr – May
Bacterial spot	May – July
Leaf mold	May – Aug

Disease	Time Period
Rhizoctonia root & crown rot	May – Aug
Early blight	June – Aug
Fusarium wilt	June – July
Southern blight	June - Aug

Numerous plant diseases can affect tomato crops in high tunnel production.

Disease Manangement for Conventional High Tunnel Tomato Production

GENERAL NOTES

The following includes an example of products; this list is not comprehensive. A complete list of fungicides and their efficacy can be found in in *Vegetable Production Guide for Commercial Growers* (ID-36) and *Southeast U.S. Vegetable Crop Handbook* (SEVEW). See Additional Resources section.

Always read product labels for specific use instructions. The label is the law.

PREPLANT

Rotate out of tomato for at least 3 years, especially for sites with a history of soil-borne diseases. Space plants for maximum air circulation. For sites with a history of timber rot, incorporate Contans into the soil in January. Follow cultural practices (rotate crops, improve drainage, select resistant cultivars, practice sanitation).

TRANSPLANT (Approximately early April)

If tunnel has a history of Rhizoctonia root rot or southern blight, apply Blocker at pre-plant, transplant, or side dress application (see precautions). Apply Ridomil for Pythium root rot and damping-off if disease emerges.

VEGETATIVE GROWTH (Approximately mid-May through mid-June)

Maintain RH below 70% by opening end or side walls for air circulation, even when raining. This is the most critical step for disease prevention and control. If above 50°F outside, it is safe to open the tunnels without damaging tomatoes. Install at least one humidity meter in each tunnel.

Sucker and prune tomato plants early while suckers are small to avoid creating large open wounds. Use clean tools. Practice good sanitation (e.g., remove diseased or senescing tissue regularly, remove clippings and debris from the tunnel).

Application Timing *Weeks after transplant*	**Application Notes**	**Fungicides/Bactericides[2]**	**Target Diseases**
Week 1 to 8	Use fungicides and bactericides preventatively before disease develops. Applications should be made every 1 to 2 weeks. Rotate products between applications to avoid resistance development.	Mancozeb	Leaf mold, leaf spots
		Coppper	
As needed[1]	Apply as a drench during April and May.	Botran	Timber rot
		Endura	
		Fontelis	
		Cabrio	
		Priaxor	
As needed[1]	Target applications in April and May.	Fontelis	Botrytis gray mold

HARVEST (Approximately mid-June to mid-August)

Maintain RH below 70% all season. Practice good air circulation. Unless there is extreme wind, the tunnel should remain open during this time period. Sanitation is critical.

Application Timing *Weeks after transplant*	**Application Notes**	**Fungicides/Bactericides[2]**	**Target Diseases**
Week 9 to 15	Applications should be made every 2 weeks. Rotate products between applications to avoid resistance development.	Fontelis	Early blight, leaf mold, leaf spots
		Quadris Top	
		Inspire Super	
As needed[1]		Inspire Super	Leaf mold
		Quadris Top	
As needed[1]		Copper	Bacterial diseases
		Actigard	
As needed[1]		Fontelis	Southern blight

[1] Application necessary when diagnostic results confirm presence of disease or if field has history of disease.

[2] See SEVEW Table 3-53 Biopesticides for alternative products. (Note: This production guide is revised annually and location of this information could change.)

Disease Management for Organic High Tunnel Tomato Production

GENERAL NOTES

The following includes an example of products; this list is not comprehensive. A complete list of fungicides and their efficacy can be found in *Vegetable Production Guide for Commercial Growers* (ID-36) and *Southeast U.S. Vegetable Crop Handbook* (SEVEW). See Additional Resources section.

Always read product labels for specific use instructions. The label is the law.

PREPLANT

Rotate out of tomato for at least 3 years, especially for sites with history of soil-borne diseases. Space plants for maximum air circulation. For sites with a history of timber rot, incorporate Contans into the soil in January. Follow cultural practices (rotate crops, improve drainage, select resistant cultivars, practice sanitation).

VEGETATIVE GROWTH (Approximately mid-May through mid-June)

Maintain RH below 70% by opening end or side walls for air circulation. This is the most critical step for disease prevention and control. If above 50°F outside, it is safe to open the tunnels without damaging tomatoes. Install at least one humidity meter in each tunnel. Sucker and prune tomato plants early while suckers are small to avoid creating large open wounds. Use a pair of shears or snips to make good cuts rather than breaking or ripping suckers by hand. Clean tools after each use. Practice good sanitation (e.g., remove diseased or senescing tissue regularly, remove clippings and debris from tunnel).

Application Timing *Weeks after transplant*	**Application Notes**	**Fungicides/Bactericides[2]**	**Target Diseases**
Week 1 to 8	Use fungicides and bactericides preventatively before disease develops. Applications should be made every 5 to 10 days.	ZeroTol OSO + Copper (tank mix) Cease/Double Nickel (or other product containing *Bacillus* spp.)	Leaf mold, leaf spots
As needed[1]	Apply as a drench during April and May.	Botrystop Howler	Timber rot
As needed[1]	Target applications in April and May.	Botrystop Cease Fracture	Botrytis gray mold

HARVEST (Approximately mid-June to mid-August)

Maintain RH below 70% all season. Practice good air circulation. Unless there is extreme wind, the tunnel should remain open during this time period. Sanitation is critical.

Application Timing *Weeks after transplant*	**Application Notes[1]**	**Fungicides/Bactericides[2, 3]**	**Target Diseases**
Week 9 to 15	Applications should be made every 5 to 10 days.	ZeroTol Cease/Double Nickel	Early blight, leaf mold, leaf spots
As needed[1]	Target applications June/July through harvest.	Copper Zonix	Leaf mold
As needed[1]		Actigard Copper	Bacterial diseases

[1] Application necessary when diagnostic results confirm presence of disease or if field has history of disease.

[2] See SEVEW Table 3-53 Biopesticides for alternative products. (Note: This production guide is revised annually and location of this information could change.)

Example high tunnel spray schedules for conventional and organic tomato production.

Conventional Production		
Weeks after Transplant	**Fungicide**	**Target Diseases**
1	Mancozeb	LM, LS
2	Copper	LM, LS
3	Mancozeb	LM, LS
4	Copper	LM, LS
5	Mancozeb	LM, LS
6	Copper	LM, LS
7	Mancozeb	LM, LS
8	Copper	LM, LS
Weeks during Harvest	**Fungicide**	**Target Diseases**
9	Quadris Top	EB, LM, LS
10	Copper	EB, LM, LS
11	Quadris Top	EB, LM, LS
12	Copper	EB, LM, LS
13	Quadris Top	EB, LM, LS
14-18	Copper	EB, LM, LS

EB – early blight; LM - leaf mold; LS – leaf spots

Organic Production		
Weeks after Transplant	**Fungicide(s)**	**Target Diseases**
1	OSO+Copper	LM, LS
2	Double Nickel	LM, LS
3	OSO+Copper	LM, LS
4	Double Nickel	LM, LS
5	OSO+Copper	LM, LS
6	Double Nickel	LM, LS
7	OSO+Copper	LM, LS
8	Double Nickel	LM, LS
Weeks during Harvest	**Fungicide(s)**	**Target Diseases**
9	OSO+Copper	EB, LM, LS
10	Double Nickel	EB, LM, LS
11	OSO+Copper	EB, LM, LS
12	Double Nickel	EB, LM, LS
13	OSO+Copper	EB, LM, LS
14	Double Nickel	EB, LM, LS
15	OSO+Copper	EB, LM, LS
16	Double Nickel	EB, LM, LS

A – anthracnose; BS – bacterial spot; RZ – Rhizoctonia; SB – southern blight

Disclaimer

Fungicides listed here include a few of the most common products available and were selected to simplify information in this publication. No endorsement is intended nor is criticism implied of similar products that are not named.

Additional Resources

- Vegetable Production Guide for Commercial Growers (ID-36)
  http://www2.ca.uky.edu/agcomm/pubs/id/id36/id36.pdf
- Southeast U.S. Vegetable Crop Handbook (SEVEW)
  https://www.aces.edu/blog/topics/vegetable-crops/southeastern-us-vegetable-crop-handbook/
- UK Plant Pathology Extension Publications
  https://plantpathology.ca.uky.edu/extension/publications

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Plant Pathology Fact Sheet **PPFS-VG-33**

Commercial Spray Schedule for High Tunnel Production of Cucumbers

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Introduction

High tunnel cucumber production allows growers to plant earlier in spring, resulting in fruit available for sale before field cucumbers can be marketed. Although high tunnels provide protection from weather and can help keep foliage dry, numerous plant pathogens can still infect high tunnel cucumbers resulting in plant and/or fruit loss. Applications of fungicides are often necessary to limit the impact from plant diseases. Fungicides provide the greatest efficacy when applied preventatively (prior to disease onset). Growers should develop a spray schedule for each season to limit the impact of the various fungi that can affect cucumbers. This document provides information on the timing of the most common high tunnel cucumber diseases, as well as an example spray schedule for conventional production systems. The fungicides recommended here include a few of the most common products. A complete list of registered fungicides can be found in V*egetable Production Guide for Commercial Growers* (ID-36) and *Southeast U.S. Vegetable Crop Handbook* (SEVEW); generic products may also be available. In Kentucky, high tunnels are considered greenhouses; use only products that are labeled for greenhouse application.

Disease	Time Period
Gray mold	Apr - Aug
Pythium root rot	Apr – Aug
White mold (*Sclerotinia*)	Apr - May
Powdery mildew	May – Aug
Southern blight	June - Aug

Table 1. Timeline of common and important diseases occurring on cucumber crops in high tunnel production.

Southern blight (*left*) and Leaf spot diseases (such as anthracnose) *(right)* can develop on cucumbers in high tunnel production.

Disease Management for High Tunnel Cucumber Production

GENERAL NOTES

The following includes an example of products; this list is not comprehensive. A complete list of fungicides and their efficacy can be found in the *Vegetable Production Guide for Commercial Growers* (ID-36) and the *Southeast U.S. Vegetable Crop Handbook* (SEVEW*).* See Additional Resources section.

Always read product labels for specific use instructions. The label is the law.

PREPLANT

Do not plant cucurbit crops in the same high tunnel year after year. Rotate out of cucurbit crops for at least 3 years in the same high tunnel, especially for sites with a history of soil-borne diseases. Space or prune plants for maximum air circulation. When available, use resistant cultivars (e.g. powdery mildew resistant cultivars). For sites with a history of white mold (*Sclerotinia*), incorporate Contans into the soil in January. Follow cultural practices (rotate crops, improve drainage, select resistant cultivars, practice sanitation).

AT PLANTING (Approximately mid-April)

Apply Previcur Flex or Ridomil for Pythium root rot and damping-off if disease emerges. To prevent bacterial wilt, manage cucumber beetles beginning at seedling stage (See *Cucumber Beetles* Entfact-311 publication)

VEGETATIVE GROWTH (Approximately mid-April through late May)

Maintain relative humidity (RH) below 70% by opening end or side walls for air circulation, even when raining. This is the most critical step for disease prevention and control. If temperatures exceed 50°F outside, it is safe to open the tunnels without risking cold damage to cucumber plants. Install at least one humidity meter in each high tunnel. Trellis plants early and prune often to maintain air circulation between plants. Clean tools after each use. Practice good sanitation, such as removing diseased or senescing tissue regularly and removing clippings and debris from the tunnel.

Application Timing *Weeks after transplant*	**Application Notes**	**Fungicides[2]**	**Target Diseases**
Week 1 to 5	Use fungicides preventatively before disease develops. Applications should be made every 1 to 2 weeks.	Mancozeb	Leaf spots
As needed[1]	Apply as a soil drench during April and May. Applications are for suppression only.	Fontelis	White mold (*Sclerotinia*)
As needed[1]	Target applications in April and May.	Fontelis	Botrytis gray mold
		Inspire Super	

FLOWERING THROUGH HARVEST (Approximately early June through mid-August)

Maintain RH below 70% all season. Maintain good air circulation. Unless there is extreme wind, the tunnel should remain open during this time period. Sanitation is critical.

Application Timing *Weeks after transplant*	**Application Notes**	**Fungicides[2]**	**Target Diseases**
Week 6 to 16	Applications should be made every 1 to 2 weeks. Rotate products between applications to avoid development of disease resistance.	Fontelis	Leaf spot, powdery mildew
		Quadris Top	
		Inspire Super	
As needed[1]	Applications should be made when disease is severe.	Torino	Powdery mildew
As needed[1]	Applications should be made when disease is severe.	Fontelis	Southern blight

[1] Application necessary when diagnostic results confirm presence of disease or if field has a history of disease.

[2] See SEVEW Table 3-53 Biopesticides for alternative products. (Note: This production guide is revised annually, and the location of this information could change with updates.)

Example field spray schedule for high tunnel cucumber production

High Tunnel Cucumber		
Weeks after Planting	**Fungicide(s)**	**Target Diseases**
1-5	Mancozeb	LS
Weeks during Harvest	**Fungicide(s)**	**Target Diseases**
6	Fontelis	LS, PM
7	Inspire Super	LS, PM
8	Fontelis	LS, PM
9	Inspire Super	LS, PM
10	Fontelis	LS, PM
11-16	Torino	PM

LS - leaf spots; **PM** - powdery mildew

Disclaimer

Fungicides listed here include a few of the most common products available and were selected to simplify information in this publication. No endorsement is intended nor is criticism implied of similar products that are not named.

Additional Resources

- Cucumber Beetles (EntFact-311)
https://entomology.ca.uky.edu/ef311
- Plant Pathology Extension Publications (UK)
https://plantpathology.ca.uky.edu/extension/publications
- Southeast U.S. Vegetable Crop Handbook (SEVEW)
https://www.aces.edu/blog/topics/vegetable-crops/southeastern-us-vegetable-crop-handbook/
- Vegetable Production Guide for Commercial Growers (ID-36)
http://www2.ca.uky.edu/agcomm/pubs/id/id36/id36.pdf

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Management of Wildlife and Domestic Animals on Your Farm

GOOD AGRICULTURAL PRACTICES

Paul Priyesh Vijayakumar, Animal and Food Sciences, and Matthew Springer, Forestry

Introduction

Good Agricultural Practices (GAPs) are necessary to ensure that fresh fruits and vegetables are harvested, handled, and packaged in a sanitary manner. Field crops are at a higher food safety risk than processed foods because of regular exposure to several sources of contamination, including soil, manure, human handling, domestic and wild animals, and water. While it is impossible to completely eliminate these risks, GAPs ensure that these risks are as small as possible when implemented correctly. For example, domestic and wild animals entering the crop production areas is a threat to food safety because animals carry human pathogens. Animals can contaminate crops and the production areas as they move through them, making it important to minimize their presence and movement in crop production areas.

Current Best Practices

Domestic/Work Animals

It is impossible to completely prevent wild animals from infiltrating the crop production areas, since they are naturally present. However, since domestic and work animals are under the farm's control, their presence and movement in and around the production areas can be monitored and controlled to an extent. Domesticated animals are allowed on the field for many reasons, including managing and deterring wildlife, pets accompanying farm operators, grazing crop residue while land is not being used for production, and for pest control such as ranging chickens or guinea fowl.

In these and similar situations, as a part of risk management, farms should have standard operating procedures (SOPs) to monitor animal tracks, deal with feces, and correct unexpected incidents where pets or farm animals gain access to production and other restricted areas. Working or draft animals should be kept away from areas where edible crops are present as much as possible. Workers handling animals on the farm also pose a risk of cross-contamination and should be trained to effectively sanitize their hands, clothes, and footwear before they handle produce. Cross-contamination could be best managed by assigning separate work crews to produce and livestock areas. If livestock are present on the farm or a neighboring farm, adequate physical or natural barriers (tree lines, ditches, cover crop) should be present to stop runoffs and prevent cross-contamination.

Wildlife Management

It's important to know the potential impact wildlife can have on your overall farming operation, especially when you are getting your GAP certification. Wildlife may be present on your farm year-round or they may only be there for short periods, such as during fall or spring migration. It is important to be aware of the associated risks wildlife and other animals may pose to production on your farm and also to understand the federal, state, and local laws that may influence how you can deal with them on your property. For more information, refer to the Natural Resources and Conservation Services at https://producesafetyalliance.cornell.edu/sites/producesafetyalliance.cornell.edu/files/shared/documents/NRCS_Produce_Safety_and_Conservation.pdf.

Wildlife and Agriculture

Controlling the presence and occurrence rates of wildlife scat or feces within your production and processing areas is a primary concern. This issue, above all else, is believed to be the main source of food contamination from wildlife and other animals.

An important aspect of all of this is the ability to identify the tracks and scat of the wildlife within your productions areas. A good mammal field guide will have pictures and descriptions that will aid you in determining what species are using your fields. Once you have identified them, you can start coming up with a plan to limit their use of production areas.

Certain species that may pose a concern to production may be protected by federal, state, or local laws. For example, most birds are protected by the federal Migratory Bird Treaty Act of 1918. Under the act, landowners may not harass or kill these species without a permit from the U.S. Fish and Wildlife Agency. However, most mammals in Kentucky fall under Kentucky Revised Statute 150.170, which allows landowners to kill any wildlife causing damage to their property. Before you start to implement any kind of lethal control on your property, contact the Kentucky Department of Fish and Wildlife Resources to determine if the species are protected.

Assessing Your Farm and Identifying Priorities

Understanding what parts of your farm are being used or will potentially be used by wildlife is important to managing wildlife in your operation. However, this can be very difficult to determine because there are so many different wildlife species present and all have different habitats, food requirements, and behaviors. The majority of wildlife damage has been shown to occur in small enclosed fields (less than 5 acres) and close to field edges where cover is present. Cover is generally woody plants or grasses that allow a specific wildlife species to remain relatively unseen and therefore adding a level of security. Paying significantly more attention to areas of your operation that fall into these categories will help you begin to identify potential areas of concern. These would also be the first areas to implement any potential deterrence or exclosures.

Walking your production areas and looking for evidence of wildlife is an important part of the wildlife section for GAP certification. You should flag any areas where you find scat in production fields. Having a plan in place to both regularly check fields for, and deal with, scat you find is an important part of the inspection. Dealing with scat can be as simple as marking and leaving it in the field and then avoiding harvesting any produce within a given distance (for instance, a 3-foot circle) around the scat.

Limiting Wildlife Use of Produce, Facilities, and Fields

To limit the possibilities of finding scat in your field, take steps to manage the situation, including installing exclosures, using deterrents, or altering the landscape around your production areas to limit available habitat.

Exclosures

Around production and agriculture buildings, exclosures such as fences and screens are the best method for keeping wildlife from causing issues with your produce. The first step is to check buildings for openings that can allow small mammals, birds, or other wildlife the opportunity to get inside. Secure problem areas you've found with small wire fencing, as small as you can obtain, to keep those wildlife out. You should check these exclosure measures regularly to make sure they are still in place and working correctly.

Fencing is another way to keep out most mammals and some birds from your production fields. Multiple fencing options exist and they can range in price from relatively inexpensive for small plots to the tens of thousands to fence in multiple acres. Be aware that although it may be a big investment to fence large areas, such as fields larger than three acres, they generally pay off with minimal upkeep costs in the long run.

Electric Fencing

Having both a portable and permanent design, electric fencing may be a good investment for producers who have smaller field (less than 2 acres) or multiple small fields (Figure 1). These fences can protect against large mammals such as deer and bears along with smaller ones such as raccoons and coyotes if you run electrified wires at both higher and lower levels. To achieve control for deer and elk, an offset design is necessary. These fences cost around $1,000 to $1,200 per acre and will last for several years. You can power them with a solar panel or connect them directly to an electric line. They take only hours to set up and can be broken down and moved to protect different crop fields as they near harvest time. Upkeep includes ensuring that plants are not touching the fence, which will cause the hot wires to be grounded, rendering the entire fence ineffective.

Figure 1. Offset electric fence design that is effective for most mammals in Kentucky. The offset is approximately 3 feet.

Figure 2. Example of a high plastic fence meant to exclude deer along with an owl decoy deterrent on the fence post to help keep birds away.

Plastic or Metal High Fences

Plastic or metal fencing taller than 8 feet will protect crops from deer and elk. Plastic fencing is less expensive than metal and is easier and cheaper to install, but it will not last as long and will need

slightly more upkeep. Plastic types of fences are good for smaller scale protection, but metal is much better to use on a larger scale.

Deterrents

Deterrents can also help keep animals out of agricultural fields. Propane cannons, balloons, predator decoys, and other scare devices are all examples of deterrents that can be implemented on a farm. However, their effectiveness decreases over time as wildlife get used to their presence. It is very hard to predict how long any of these methods work. You should move or change deterrents every few days to keep wildlife from getting used to them too quickly. Simply moving a deterrent in and around your field can give you a few more days of effectiveness.

Spray deterrents and other homemade remedies are not recommended, because their effectiveness is unproven.

Habitat Modification

Modifying the areas around productions fields is one of the most effective ways to control wildlife. Eliminating hedgerows, forested areas, and tall grasses around your fields will cut back on comfortable places for animals to hide and live near your production areas.

Population Control

When dealing with larger species such as white-tailed deer, your strategy may need to include population control by hunting on your property. This approach only works if hunters are consistently harvesting large numbers of females during the hunting season. The same holds true for smaller species such as raccoons, where harvesting females in the winter will help lower overall raccoon numbers the following spring.

Recommendations

It is important to routinely check production areas for the presence of wildlife and identify which species are there. Determine how often they are there and whether their presence affects your production. Train your farm staff in wildlife track and scat identification and have a field guide on hand to help. If animals are regularly showing up where you do not want to see them, you may need to change the habitat, place deterrents, or build exclosures as needed.

Conclusion

Domestic and work animals are beneficial to the farm in many ways, but since they can harbor human pathogens, they are a major source of contamination. Proper risk management, aided by SOPs and procedures to track animal movement, take care of animal droppings, and enforce proper sanitation practices for personnel and equipment can minimize food safety risks.

No matter how your farm operates, wildlife will always be an issue, from large farms to those completely in high tunnels. Understanding how different animals behave and respond to stimuli may help limit the impact wildlife have on your farming operation.

Wildlife can be beneficial or problematic for agriculture. Negative impact of wildlife is well known, with many different species causing direct damage to plants through consumption or trampling. However, it is easy to forget that wildlife can aid in agriculture production, such as the role of pollinators and resulting impacts they can have on crop yields. With this in mind, it is important to strike a balance while trying to manage your farm for wildlife.

Know the cost and benefits of multiple techniques of wildlife control, all of which will vary depending on your personal situation. Exclosures and habitat modification are generally the most effective methods to help limit wildlife-related issues in an agricultural landscape. It is important to remember that removing all wildlife habitat from your farm has the possibility of being costlier in the long run as those areas tend to have multiple and sometimes beneficial effects on your farm environment, including soil and water conservation.

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