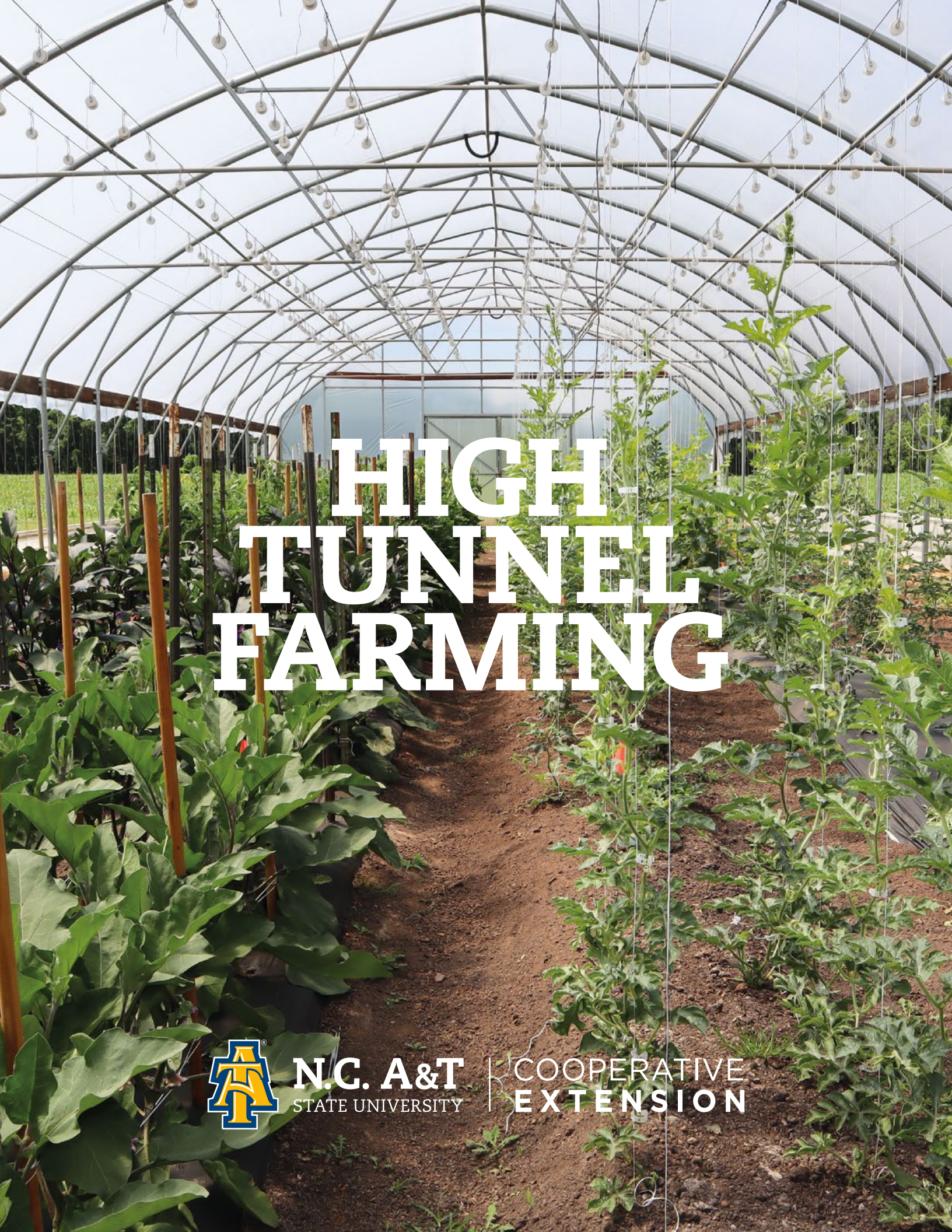

HIGH TUNNEL FARMING

N.C. A&T STATE UNIVERSITY | COOPERATIVE EXTENSION

HIGH TUNNEL FARMING

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High Tunnel Basics

WHAT IS A HIGH TUNNEL?

- High tunnels are unheated, plastic-covered structures that provide an intermediate level of environmental protection and control, compared to open field conditions and greenhouses.
- In a high tunnel, sunlight is usually the sole heat source.
- A high tunnel needs to have two straight side walls (usually 4-8 feet high) so people can walk upright, work comfortably and use small machines inside.
- A high tunnel structure can be interchangeably used as a hoop house or a cold frame, although the latter may not have side walls.

Picture 1-1: A high tunnel in snow (left) and row covers used inside a high tunnel for extra frost protection (right).

Picture 1-2: Warm-season vegetables (cucumbers and tomatoes, left) and cool-season vegetables (right) growing inside high tunnels.

WHY SHOULD YOU INVEST IN A HIGH TUNNEL?

A high tunnel can provide farmers with the following benefits:

- Lower start-up costs compared to a greenhouse.
- Significantly longer growing and marketing seasons compared to the field—the frost-free days inside a high tunnel add at least four to six weeks to the seasons.
- Better ability to grow cold-hardy vegetables (vegetables resistant to cold temperatures) through winter in most regions of North Carolina.
- A lower chance of diseases that need free water to spread because high tunnels keep rain away.
- Less wind stress and ultraviolet light that can damage plants. This improves the quality of produce.
- Faster growth and earlier maturity, so you can harvest your crops earlier compared to the same crops grown outside.
- Higher marketable yield.
- Better conditions for best management practices, such as using plastic mulch and drip irrigation.
- Easier adoption of organic practices compared to the field, such as biological control of insect pests and organic soil amendments.
- More even distribution of labor throughout the year because farm workers can work inside a high tunnel during cold weather.

High tunnels also provide a lot of flexibility. For example, shade cloth can be added for summer production and insect screens can be installed to prevent insect pests from getting in. Electric power or solar panels can be installed to provide cooling and ventilation. Commercial high tunnels can also be converted to greenhouses for even more environmental controls.

Unlike greenhouses, high tunnels are not considered permanent structures for tax purposes. The USDA's Natural Resources Conservation Service (NRCS) offers a High Tunnel Cost Share Program that supports up to one-twentieth of an acre high tunnel. That equals up to 2,178 square feet, or a high tunnel of about 30-feet wide by 72-feet long.

High tunnels are not for everyone. Some disadvantages to using a high tunnel include the following.

- A high tunnel adds extra structure and construction costs compared to the typical field production system.
- High tunnel production is labor intensive.
- Environmental protection from a high tunnel is limited. Extreme weather conditions could be disastrous to high tunnel structures and crops.
- The ability to irrigate in high tunnels is a must.
- If not appropriately managed, pests, including insects, spider mites, diseases and weeds, can become challenges inside a high tunnel.
- Due to a lack of rainfall, fertilizer salts may build up over time.

TYPES OF HIGH TUNNELS AND CROPS THAT PERFORM WELL IN THEM

There are different ways to categorize a high tunnel.

- High tunnels can be single-bay or multi-bay, depending on the number of bays (the hoop structure) they have.
- They can be a gothic or Quonset type, based on the shape of the hoop structure.
- High tunnels can be designed and set up as moveable or as fixed or stationary.
- Some high tunnels are homemade while others are made from commercial high tunnel kits.

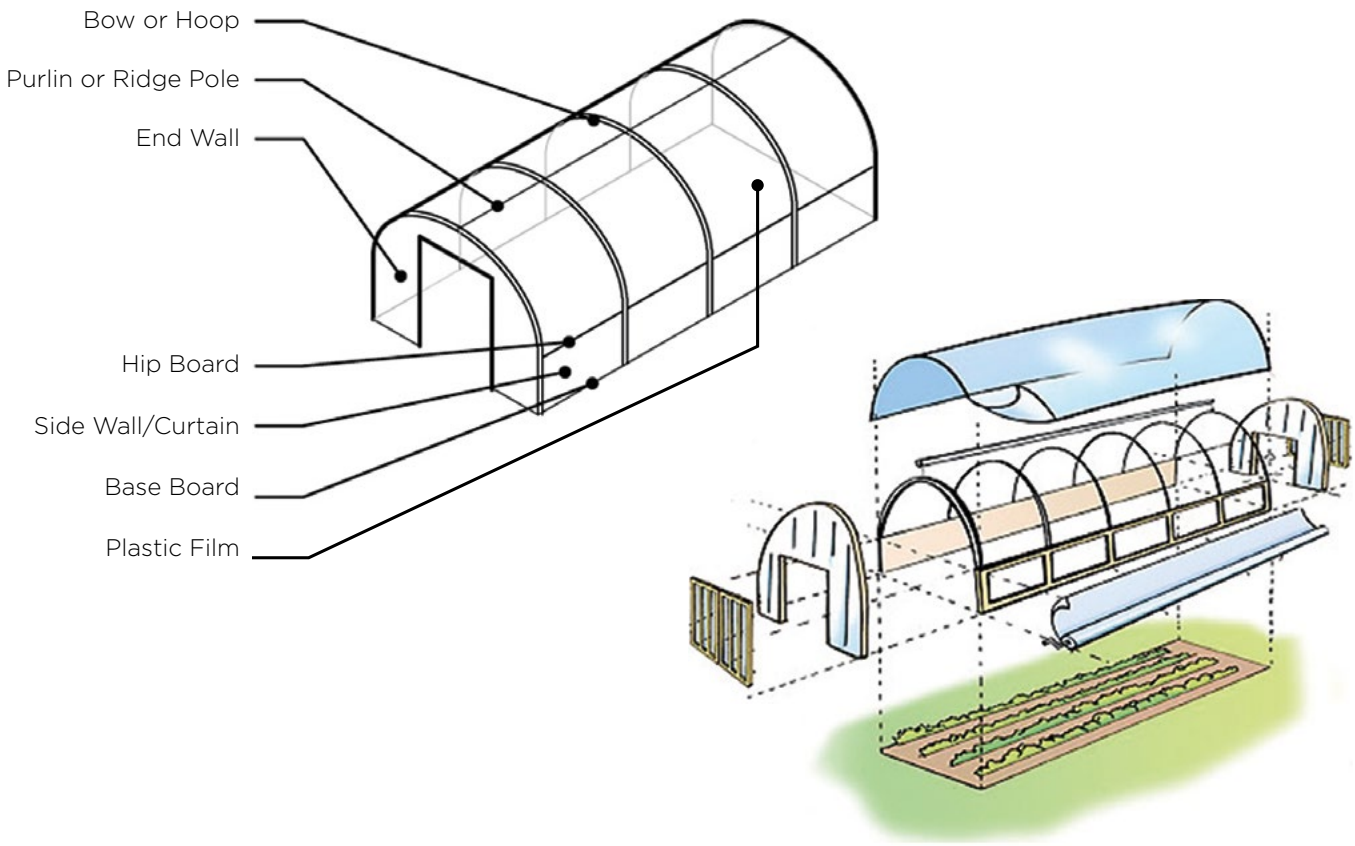
Picture 1-3. Single-bay high tunnels at the N.C. A&T University Farm. From left to right: A Quonset and gothic hybrid fixed high tunnel, two Quonset fixed high tunnels (tandem), and two gothic moveable high tunnels (side-by-side). Photo by John Kimes.

Different crops are suited for different types of high tunnels.

- A single-bay high tunnel is typically for annual crops such as vegetables and flowers.
- A multi-bay high tunnel can grow annual crops as well as perennial crops such as small fruits.

BASIC STRUCTURE OF A SINGLE-BAY HIGH TUNNEL

The basic structure of a single-bay high tunnel consists of bows or hoops or ribs, side posts that connect to the hoops and side curtains, purlins or ridge poles, end walls, hip boards, side walls or curtains, baseboards, and one or two layers of plastic films. There is usually a door or two built into the end walls.



Picture 1-4: The structure of a single-bay high tunnel.
Images courtesy of hightunnels.org and Missouri Cooperative Extension.

HIGH TUNNEL COST AND PROFIT EXPECTATIONS

- The material cost of a single-bay high tunnel ranges from 50 cents to $3.50 or more per square foot.
- Construction costs can be up to 60% of the material costs.
- The profit expectation in high tunnel production is to have $5 to $10 per square foot net income each year.
- Given the cost of materials and labor, a farmer can expect an investment in a high tunnel to pay off in less than two years. Most farmers are able to get their investment back on a high tunnel structure in about a year.

HIGH TUNNEL ENVIRONMENT

Air temperature: A high tunnel provides a warmer environment compared to open field conditions.

- The lowest temperature inside a high tunnel can be 10 to 20° F higher than outside temperatures, which moves up *plant hardiness zones* (planting zones designated by the USDA) by one or two zones, providing a subtropical or tropical climate.
    - o The temperature protection ability of high tunnels is affected by how well the tunnel is built and sealed. A poorly built structure may only provide a couple of degrees of temperature protection compared to outdoor temperatures.
- The *freezing temperature* (32° F) in high tunnels is delayed by about a month in the fall and the last freeze comes almost two months earlier in the spring. It is safe to say that high tunnels can extend the growing season by 30 to 45 days at each end of the season.
- *High temperatures* in high tunnels can be high enough to cause heat damage even in winter.

Soil temperatures: Soil temperatures in high tunnels rarely fall below 40° F, which means the possibility of growing cold-tolerant crops over winter. However, because soil temperatures in high tunnels can fall below 50° F, growing warm-season crops in winter is impossible, even in the coastal plains of North Carolina.

Light: A single-layer plastic film (the regular 6-mil greenhouse-grade plastic) can block up to 30% of photosynthetically active radiation (PAR, 400-700 nm wavelength) and 25% of solar radiation of 300 to 1100 nm wavelenth from entering a high tunnel. A double-layer plastic can block half of PAR and SR.

Humidity: The relative humidity inside a high tunnel is often high after irrigation takes place, but ventilation can reduce the humidity. The hours of leaf wetness are rarely long enough to induce diseases.

CHOOSING A HIGH TUNNEL

A high tunnel can be constructed from a commercially-made kit or homemade from locally available materials.

- A grower should consider purchasing a prefabricated high tunnel kit to avoid figuring out everything on their own.
- If the high tunnel is acquired through the cost-share program from NRCS, it needs to be a commercial kit. It is essential to consult with your NRCS agent and get approval before ordering a high tunnel kit.

Why does film plastic sometimes deteriorate where it contacts the high tunnel structure?

Film plastic is often weakened when in contact with greenhouse structural components, especially PVC framing materials. The background on this starts with the green tint greenhouse films produced from 1960 through the early 1980s, which used a nickel-based ultraviolet (UV) stabilizer that was not affected by free chlorine, fluorinated hydrocarbons, and the volatile plasticizers found in PVC. By 1983, long-life films were UV-protected not by the nickel-based UV-stabilizer, but by clear UV-inhibitors called "hindered amine light stabilizers" (HALS). These films had high clarity and did not darken with age. One of the drawbacks with the HALS UV-stabilizers is that as the film is exposed to free chlorine, fluorinated hydrocarbons, selected pesticides, sulfur, and volatile plastizers found in PVC pipe, the stabilizer complex becomes inactivated. When this happens, the life of the greenhouse film is shortened, especially where it contacts the PVC. For this reason, all polyethylene manufacturers do not advocate direct contact of long-life polyethylene with PVC pipe. Sisal baler twine, which is often used for plant support and may be tied to the purlins for this function, can also cause breakdown of polyethylene. The petroleum-based preservative will, over time, degrade the polyethylene.

To prevent this deterioration, some farmers choose to paint PVC bows with latex paint on the interface with plastic film.

(Modified from hightunnels.org.)

When building a homemade high tunnel:

- Begin by finding information on high tunnel design. This information will serve as a reference and save valuable time.
- There are many types of homemade high tunnel designs online, developed for specific purposes by the designers.
    - A PVC (polyvinylchloride) pipe high tunnel is not recommended for commercial production. It has a higher risk of collapsing in heavy snows and wind gusts. PVC expands and contracts with temperature and deteriorates over time. Farmers may lose their warranties on plastic film on a PVC pipe structure.
    - Examples of good high tunnel design are the Quick Hoops™ high tunnels by Johnny's Selected Seeds. These tunnels are made from galvanized electrical conduits that are available from local hardware stores. The company has detailed instructions on bending the conduits with specific benders and step-by-step construction guides.
        + For detailed information, please visit *http://www.johnnyseeds.com/tools-supplies/greenhouse-and-tunnel-supplies/benders/.*
        + Instruction Manual for 7300 Quick Hoops™ Gothic High Tunnel Bender: *http://www.johnnyseeds.com/growers-library/tools-supplies/7300-qh-stationary-gothic-high-tunnel-bender-instruction-manual.html?q=bender*
        + Supplemental instruction for 7300 Quick Hoops™ Gothic Tunnel Bender: *http://www.johnnyseeds.com/growers-library/tools-supplies/7300-qh-modular-moveable-gothic-cathedral-tunnel-instruction-manual.html?q=bender*

When installing commercial high tunnels:

- Choose an experienced company. A greenhouse or a high tunnel company started before the NRCS Environmental Quality Incentives Program would naturally have more experience in high tunnel design and construction.
- In areas where heavy snow and strong winds are common, choose a gothic design, drop-down curtains, and heavy-duty materials for your high tunnel.
    - Ridge ventilation is not a good option in windy and snowy areas.
- It is often a good idea to consider extra structure supports and automation when choosing a high tunnel.
- Contact several companies for technical details and construction guides.
    - A well-designed, step-by-step construction guide is very important.
    - Some companies have some materials pre-drilled, so the construction will be much easier.
    - Check with the companies for construction options.

Single-bay high tunnel examples:

- Atlas: *https://atlasgreenhouse.com/greenhouses/cold-frame-series-2/*
- FarmTek: *https://www.farmtek.com/farm/supplies/cat1a;ft_high_tunnels_cold_frames.html*
- Four Season Tools: *https://www.smallfarmtools.com/pages/high-tunnels*
- Harnois Industries (Canada): *https://www.harnois.com/en/greenhouses/tunnels/*
- Puckett: *http://www.puckettgreenhouses.com/*
- Rimol: *http://www.rimolgreenhouses.com/greenhouse-series/high-tunnel*
- Zimmerman's: *http://www.zimmermanshightunnels.com/* or through Morgan County Seeds *https://www.morgancountyseeds.com/product-category/buildings-equipment-supplies/buildings/high-tunnels/*

Multi-bay high tunnel examples:

- HayGrove: *https://www.haygrove.com/polytunnels/*
- Harnois Industries: *https://www.harnois.com/en/greenhouses/tunnels/*

Notes:

High Tunnel Construction

SITE SELECTION

A high tunnel is not considered a permanent structure. However, once constructed, a high tunnel is relatively stable in its location, even if it is a moveable high tunnel. A high tunnel usually sits at its original location for at least four to five years if not designed to be moveable. Most farmers do not move a high tunnel to a different location, although this option remains open in case relocation becomes necessary.

The following factors are necessary to consider when choosing the location for a high tunnel:

- ***Ample sunlight:*** A location without shade from surroundings at the winter solstice is ideal.
- ***Accessible to water:*** It is essential to have a water supply for high tunnel production.
- ***Level land:*** The grade of your land should be less than 3% along the length of the high tunnel.
  - o Avoid grading that may significantly impact soil structure and top soil.
- ***Good soil:*** High tunnels work best in loamy soil with high fertility and organic matter content, no history of perennial weeds or diseases and no large stones.
- ***Good drainage:*** Avoid draining into the tunnel.
- ***Free of frost pockets:*** A frost pocket is a location where cold air collects, leading to frost.
- ***Accessible to electricity:*** Electric power is desirable, especially with a double-layer poly high tunnel.
- ***Natural windbreaks:*** A high tunnel should be away from locations with strong gusty winds. A location with natural windbreaks that will not shade the high tunnel is desirable.
- ***Snow:*** In areas of heavy snow, it is essential to have a place to dump snow removed from the high tunnel. If there is a windbreak, it should be designed so that snow will not pile up and block your high tunnel.
- ***Wild animals:*** Wild animals can be devastating to high tunnel crops.

ORIENTATION

In areas below 40º north latitude, high tunnels should have a north-south orientation to capture more lights. This includes all of North Carolina. However, exact orientation is location-specific. That means in a given location, the direction of the prevailing winds could be a factor in determining adjustments to your orientation. The prevailing winds should strike your high tunnel directly on a side wall. In other words, the length of your high tunnel should be perpendicular to prevailing winds.

- If installing multiple bay structures, a N-S orientation will prevent shading of adjacent tunnels.

KEY CONSTRUCTION POINTS

Farmers should check with their local county government about building codes for high tunnels.

- It is essential to explain to government officials that high tunnels are not considered permanent structures.
- When constructing a high tunnel, try to assemble things on the ground level as much as possible.

The construction steps vary between different models of high tunnels, but the necessary steps are similar and listed below.

- Prepare the site, gather tools, machines, and laborers
- Drive end posts and side posts into the ground.
- Assemble bows.
- Install bows to the end posts (for end walls), line or side posts (for side walls) and to end posts at the other end of the tunnel.
- Install hip boards and baseboards.
- Install side curtains.
- Install purlins, braces, trusses, etc.
- Install end walls and doors.
- Cover high tunnels with poly-plastic films.
- Install optional systems, such as ventilation and gutters.

STEP-BY-STEP HIGH TUNNEL CONSTRUCTION

High tunnel construction illustrated with a 30-foot by 96-foot high tunnel with ridge vent

1) Site preparation: Grade the area as needed. Ideally, the site will be slightly elevated compared to the surrounding area. Insert flags in the ground where the posts will go (posts should be either 4 or 6 feet apart). A simple method is to use a "3-4-5" process (Pythagorean theorem) to locate the four corners of a high tunnel. To do so, flag one corner, measure out 30 feet (the width of the high tunnel) and flag, and then measure 40 feet along the side and flag (Picture 2-1). The measured space between the two flags should be exactly 50 feet. Once the four corners are marked, insert a flag every 4 or 6 feet along the long side of a high tunnel.

Picture 2-1: Measuring and flagging a high tunnel site.

2) Get tools ready: Gather necessary tools (Picture 2-2). Make sure there is electricity available to recharge batteries of drills and other tools.

Picture 2-2: Having all your needed tools available at the start makes high tunnel construction easier.

The tools for high tunnel construction vary but will likely include the following items:

- Adjustable wrenches
- Circular saw
- Clamps
- Cordless drills or drivers
- Drill bits
- Eye and ear protection
- Hoes
- Impact bits
- Large and small sledges
- Laser transit
- Mattocks
- Pliers
- Post levelers
- Post pounder (hand, gas, or air-powered)
- Post puller
- Reciprocating saw
- Reel measures
- Ropes and tennis balls (for pulling poly)
- Scissors
- Shovels
- Tall adjustable ladders
- Tape measures
- Tractor with loader
- Wire cutters
- Wooden stakes

Indiana High Tunnel Handbook, 2018

3

3) Drive in side wall posts: Using a post driver will significantly help with this process (Picture 2-3, left). If you do not have access to a post driver, consider hiring a professional to do the post driving work (Picture 2-3, right). Drive in the corner posts first and tie a string to the two end posts so all the posts will line up. In windy areas or in sandy soil, consider adding concrete to at least the four corner posts.

Picture 2-3: Installing side wall posts using a post driver.
Left: a post driver for 6-foot or less tall side wall posts;
Right: a post driver for side wall posts that are taller than six feet.

4

4) Assemble bows: Assemble bows whenever the time is available. Find or make a level ground base, measure out 30 feet, and mark the two ends. Drive in two metal tubes at each end so the bow can be placed between (Picture 2-4, left). Lay out pieces and mark as needed (such as for V or W trusses), and assemble them (Picture 2-4, middle and right). Keep in mind that the first and last bows do not have braces because the end walls will be built upon them later.

Picture 2-4: Assembling bows for high tunnel construction.

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5) Install bows onto the line posts: Photo on the left in Picture 2-5 shows the first bow of a high tunnel with ridge vent. Photo on the right shows bows without ridge vents. Please note the difference between the first and the second bows in the photo on right.

Picture 2-5: Connecting bows onto the side posts.

6

6) Install purlins, braces, trusses and other supporting structures (Picture 2-6).

Picture 2-6: Connecting bows with purlins and installing w-trusses and braces.

7

7) Install hip boards and base boards (Picture 2-7).

Picture 2-7: Laying out base and hip boards and attaching them to the side posts (upper); Installation of hip and base boards completed (lower).

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8) Install c-channels on the hip board (Picture 2-8): This is done to fasten the plastic films.

Picture 2-8: Installing c-channels on the hip board.

9) Install side curtains (drop-down curtains): First, install anchors, hooks and pulleys; then install pulling steel cord (through the hooks) and the protecting nylon strings (Picture 2-9). Attach corner curtains, insert metal rod into the curtain, and attach the rod to the hip board through pulleys (Picture 2-10). Lastly, nail the lower side of the curtain to the baseboard (Picture 2-11), and install the outside protecting nylon strings.

Picture 2-9: Installing anchors, hooks and pulleys on the hip board, inserting steel cords through the hooks, and then nailing the nylon string on the hip board and base board.

Picture 2-10: Attaching corner curtains (the white curtain in the left photo), inserting metal rod into the curtain (connecting rods as a rod is about to be inserted into the curtain), and attaching the rod with strings to the hip board through pulleys.

9) Install side curtains (drop-down curtains), continued:

Picture 2-11: Nailing the lower side of the curtain to the base board (left). A completed side curtain (right) after installing the outside protecting nylon strings.

10) Install ridge vent (optional): Please note designs of ridge ventilation vary significantly depending on the company that makes them. For safety, use a cherry picker or similar safety unit to work on a high tunnel (Picture 2-12).

Picture 2-12: Installing ridge vent.

11) Build end walls: These can be made of lumber or steel. Measure the length needed for lumber or steel based on your end wall design (Picture 2-13). On-site cuts of lumber or steel are often necessary.

Picture 2-13: Constructing end walls. Left, on-site measuring for the length of vertical bars; Right, a completed end wall frame.

12) Install poly plastic films on the roof (with ridge vent): This step can be done either before or after covering the end walls. There are two pieces of films for high tunnels with a ridge vent, the installation process is the same.

First, lay out the film and unfold it on the ground (do not step on the film anytime), then use wiggle wires to secure the plastic film into the c-channels on the hip board (Picture 2-14);

Picture 2-14: Laying plastic film on the ground and securing the plastic film to the c-channels on the hip board with wiggle wires.

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12) Install poly plastic films on the roof (with ridge vent), continued: Second, tie a piece of 1-inch x 2-inch lumber or similar materials (a piece of c-channel was used in the photo) every 10 to 12 feet to another side edge of the plastic, tie a rope to each lumber, and pull the plastic over the roof from the other side of the high tunnel (Picture 2-15).


Picture 2-15: Tying the plastic film and pulling the rope to pull the plastic film over the roof.

Third, secure the plastic with wiggle wires into the c-channels on the ridge vent.


Picture 2-16: Securing the plastic film to the ridge vent (left), and putting on the second piece of plastic film.

Lastly, install the second piece of plastic (Picture 2-17). If using double-layer plastic film, install the second layer of plastic over the existing plastic (Picture 2-17).


Picture 2-17: Putting on the second layer of plastic film if your high tunnel has double-layer plastic cover.

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13) Install plastic on end walls and install doors. Please note that Pictures 2-18 and 2-19 show plastic film coverings on a tunnel with and without a ridge vent, respectively.

Picture 2-18: Putting plastic on end walls from the bottom (left). Plastic is secured into c-channels on the end wall with wiggle wires. The photo on the right shows a completed end wall before cutting the extra plastic.

Picture 2-19: Putting plastic on end walls for a high tunnel without a ridge vent.

High Tunnel Crop Choices

In most parts of North Carolina, it is possible to grow and harvest at least one warm-season crop and one cool-season crop each year. The long growing season, the high number of crop species and their cultivars, and the abundant opportunities to grow two or more crops in close proximity (intercropping) make high tunnel crop choices flexible and complicated.

Almost all vegetables and small fruits can grow and produce in high tunnels. However, *not all species are profitable*. Consider the following when choosing your high tunnel crops.

- Choose crops that fit your market and your production system.
    - o A farmer who markets through a CSA (Community Supported Agriculture) system usually grows more crop species than one who markets directly through farmers markets or farm stands.
    - o Wholesale farmers grow fewer crop species but on a larger scale than retail farmers.
- When choosing a crop, consider its productivity per square foot because high tunnel space is valuable. Also, consider using the vertical space in your high tunnel.
    - o Do not grow crops like winter squash that require lots of space. Although they can grow and produce well in high tunnels, the space required usually makes them less profitable.
    - o Trellis high-value vining vegetables such as cucumbers and melons for efficient use of both vertical and horizontal space.
    - o Crops requiring extensive pollinations by pollinators, such as bees, may have low yield or fruit quality in a high tunnel. Choosing parthenocarpic (seedless) cultivars will solve the problem.

SINGLE-BAY VS. MULTI-BAY HIGH TUNNELS

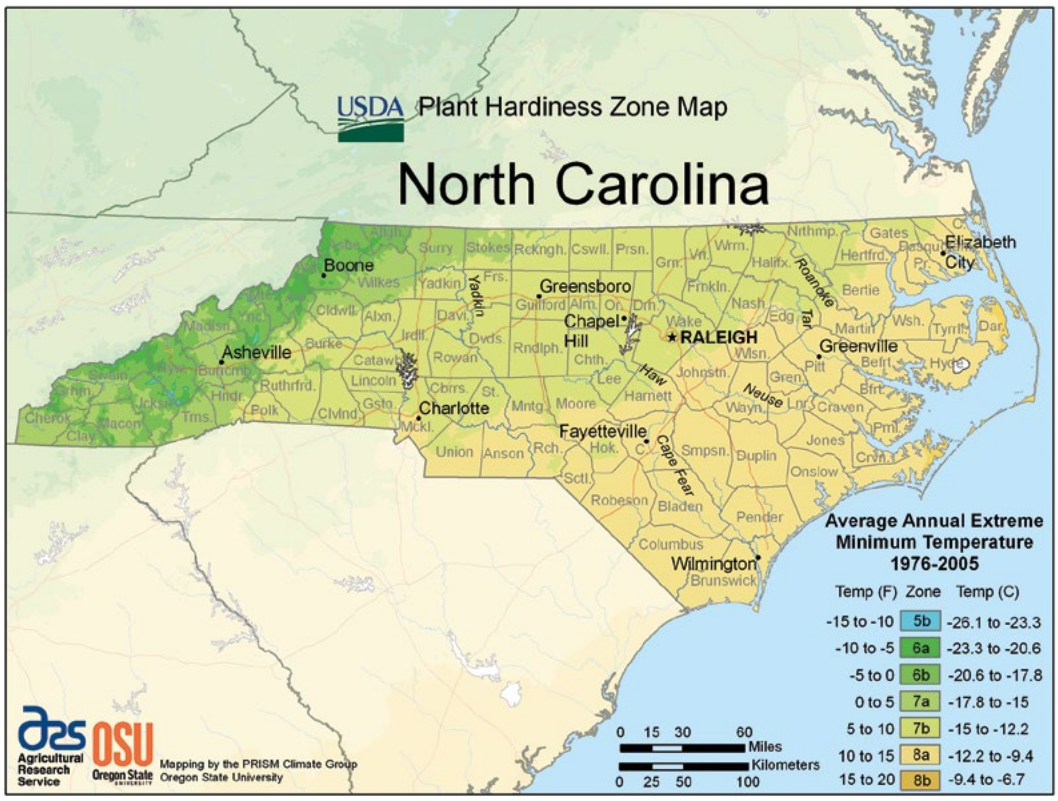
- Use single-bay high tunnels to produce annual vegetables, flowers and strawberries.
- Use multi-bay high tunnels to grow annual but non-overwinter vegetable crops such as tomatoes, peppers, eggplants and cucumbers, perennial small fruits such as blackberries, raspberries and blueberries, and either annual or perennial strawberries.

Picture 3-1: Eggplants and watermelons in a single-bay high tunnel (left) and blackberries in a multi-bay high tunnel (right).

Crops that have a premium from early harvests such as tomatoes, cucumbers, peppers, berries or salad greens are top choices for high tunnel production.

- Fruiting vegetables such as tomatoes and seedless cucumbers tend to have higher market values.
- In Hardiness Zones 5 and 6 in the Midwest, a survey showed the top vegetable species for high tunnels to be tomatoes, lettuce, spinach, cucumbers, leafy greens, flowers, beans, squash, strawberries, onions, melons, broccoli and eggplant.
- In Hardiness Zone 7, which includes most of the South, farmers reported growing cucumbers, kale, lettuce, tomatoes, spinach, carrots, beets, peppers, Chinese cabbage, buss beans, eggplant, peas, strawberries, broccoli, summer squash (zucchini) and melons.
- A survey conducted in 2014 indicated that North Carolina farmers had grown tomatoes, lettuce, cucumbers, peppers, carrots, spinach, leafy greens, Swiss chard, onions, beets, radishes, beans, cabbage, turnips, zucchini and herbs in high tunnels.

Plant Hardiness Zone Map



The Agricultural Research Service of USDA created the Plant Hardiness Zone Map using the historical average annual minimum winter temperatures. The latest map was released in 2012 and divided into 10° F Zones *(http://planthardiness.ars.usda.gov/PHZMWeb/Default.aspx)*. There are 13 Zones in the U.S. In North Carolina, the Zone number ranges from 5 to 8 (Figure 1). Each Zone is divided further into two 5° F Sub-Zones (a and b). Using the map, growers can determine which plants are most likely to thrive at a location.

Figure 3-1: The Plant Hardiness Zone Map for North Carolina.

SPECIALTY CROPS TO CONSIDER

Some tropical and subtropical crops can successfully grow in high tunnels.

- Niche crops such as baby ginger, turmeric (Picture 3-2), and green papaya are profitable crops for some farmers in North Carolina and Virginia.
- Figs and table grapes are also successful crops for some farmers.

Picture 3-2: Organic ginger, galangal and turmeric in a high tunnel on the N.C. A&T University Farm.

For each crop species, there are early, medium and late cultivars available. To take advantage of the season extension capacity of high tunnels, many farmers prefer early cultivars that can provide early yields.

- Choose a combination of early, medium and late cultivars so a consistent supply of produce will be available to markets.

Tomatoes have consistently been one of the top five high tunnel crops. ***If you can't decide which crop to grow, start with tomatoes.*** Alternatively, plant cover crops (Chapter 5) to improve your high tunnel soil.

High Tunnel Crop Planting Calendar

FROST-FREE DAYS

As a farmer, you need to know your field growing season, which is closely related to the frost-free days in your region. The days between the last spring freeze (Figure 4-1) and first fall freeze (Figure 4-2) equals your frost-free days.

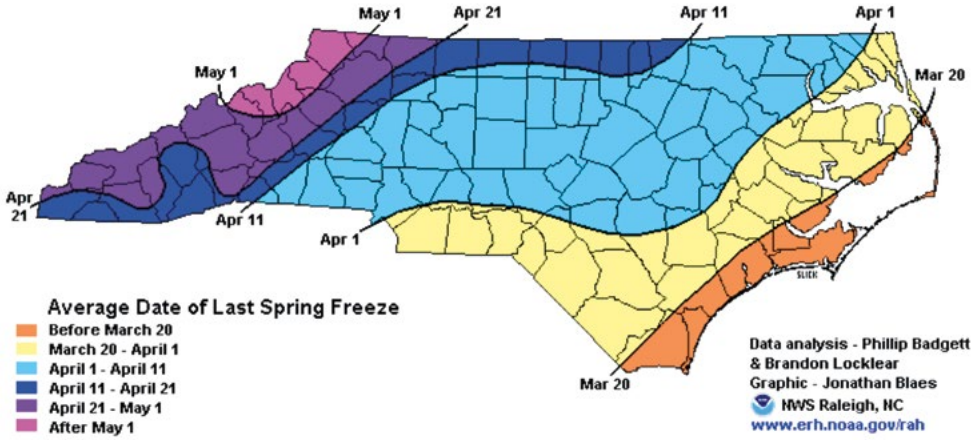


Figure 4-1: The average last spring freeze in North Carolina

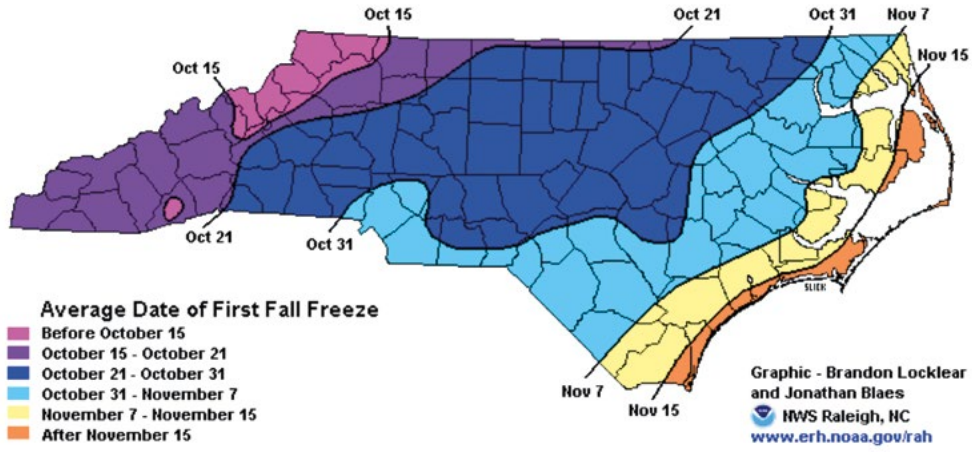


Figure 4-2: The average first fall freeze dates in North Carolina

PLANTING DATES

The planting dates of high tunnel crops are dependent on the crops you grow and your farm location. Suggested planting calendars follow on pages 27, 28 and 29.

Hot-Season Vegetables

Hot-season vegetables are intolerant of cool weather, will not thrive below a mean temperature of about 70º F, and will not grow much under 50º F.

- Hot-season vegetables include eggplant, English cucumbers, hot peppers, okra, melons, watermelons, ginger and turmeric.
  - o Transplant two to four weeks earlier than when growing these crops outdoors.
  - o These plants can produce throughout the summer in a high tunnel.
  - o The last harvest will be around the time of the first fall field frost.

Warm-Season Vegetables

Warm-season vegetables are intolerant to frost. These crops thrive in monthly mean temperatures of 65-80º F.

- Cucumbers (excluding English cucumbers), muskmelons, summer squash, beans, bell peppers, tomatoes and sweet corn are crops in this category.
  - o Transplant four to six weeks earlier than when growing these crops outdoors. Beans, which will be directly seeded, are an exception.
  - o The plants will produce throughout the summer if some shade is provided.
  - o The last harvest will be around two to four weeks after the first fall field frost.

Cool-Season Vegetables

Cool-season vegetables are intolerant to freezing but can tolerate frost under certain conditions. These crops grow best with a monthly mean temperature of 55-75º F.

- Onions, garlic, leeks, shallots, cauliflower, broccoli, lettuce, celery, carrots, potatoes and peas fall into this category.
  - o Garlic, potatoes, peas and carrots should be directly seeded.
  - o Broccoli and cauliflower crowns will tolerate a freeze if the flower/curd is not developed.
  - o For spring planting, transplant six to eight weeks earlier than when growing these crops outdoors.
  - o For fall planting, transplant between four weeks before and two weeks after the first fall frost.
  - o Plants will not produce in summer or deep winter, although plants will not die if covered with row covers in winter.
  - o Expect the last fall harvest around the start of the new year.

Cold-Season Vegetables

Cold-season vegetables are intolerant of monthly mean temperatures of 70-75º F and prefer cooler temperatures of 60-65º F. Crops can survive freezing weather in high tunnels.

- Crops in this category include spinach, beets, turnips, kohlrabi, Brussel sprouts, kale, cabbage, collards, Chinese cabbage and some Asian greens such as tatsoi and pac choi.
  - o Plants can grow throughout the winter under row covers.
  - o There is a long window of sowing or transplanting for these vegetable crops.
    - + The first planting/sowing date is around the time of the first fall frost.
    - + The last planting/sowing month is October in Zone 6, November in Zone 7, and December in Zone 8 and above.

High Tunnel Strawberries

Transplant strawberry plugs from September to October, depending on your location.

- o You can follow the field strawberry planting date or plant two to three weeks after the suggested field planting date.
- o Harvest starts in late February and runs through the end of April. Day-neutral strawberries will begin to produce harvestable fruit in January.

Baby Ginger and Turmeric

Raise ginger transplants indoor (greenhouse preferred) in January.

- Transplant in April.
- Harvest baby ginger in September and until frost develops inside the high tunnel.
  - o North Carolina does not have a long growing season for mature ginger in high tunnels.

Following are detailed planting calendars for the mountains (Figure 4-1), Piedmont (Figure 4-2) and coastal plains (Figure 4-3) of North Carolina.

Notes:

Planting Calendar for N.C. Mountains

Category	Crop	Type	Jan			Feb			Mar			April			May			June			July			Aug			Sept			Oct			Nov			Dec		
			1	11	21	1	11	21	1	11	21	1	11	21	1	11	21	1	11	21	1	11	21	1	11	21	1	11	21	1	11	21	1	11	21	1	11	21
Cold season	Spinach, beets, turnips, tatsoi, pac choi, pea (shoots), Swiss chard, greens	Direct Seed																																				
		Harvest																																				
	Spinach, Brussels sprouts, kohlrabi, kale, cabbage, Chinese cabbage, tatsoi, pac choi	Transplant																																				
		Harvest																																				
Cool season	Carrot, green onion, potato, pea (pods)	Direct Seed																																				
		Harvest																																				
	Onion, garlic, leek, shallot, cauliflower, broccoli, lettuce, celery	Transplant																																				
		Harvest																																				
Warm season	Beans, sweet corn	Direct Seed																																				
		Harvest																																				
	Cucumber, muskmelon, summer squash, bell pepper, tomato, sweet corn	Transplant																																				
		Harvest																																				
Hot season	Eggplant, English cucumber, hot pepper, cherry tomato, okra, watermelon, ginger, turmeric	Transplant																																				
		Harvest																																				

Figure 4-1: Suggested vegetable planting calendar for mountains of North Carolina

Planting Calendar for N.C. Piedmont Region

Category	Crop	Type	Jan 1	Jan 11	Jan 21	Feb 1	Feb 11	Feb 21	Mar 1	Mar 11	Mar 21	April 1	April 11	April 21	May 1	May 11	May 21	June 1	June 11	June 21	July 1	July 11	July 21	Aug 1	Aug 11	Aug 21	Sept 1	Sept 11	Sept 21	Oct 1	Oct 11	Oct 21	Nov 1	Nov 11	Nov 21	Dec 1	Dec 11	Dec 21
Cold season	Spinach, beets, turnips, tatsoi, pac choi, pea (shoots), Swiss chard, greens	Direct Seed																																			
		Harvest																																			
	Spinach, Brussels sprouts, kohlrabi, kale, cabbage, Chinese cabbage, tatsoi, pac choi	Transplant																																			
		Harvest																																			
Cool season	Carrot, green onion, potato, pea (pods)	Direct Seed																																			
		Harvest																																			
	Onion, garlic, leek, shallot, cauliflower, broccoli, lettuce, celery	Transplant																																			
		Harvest																																			
Warm season	Beans, sweet corn	Direct Seed																																			
		Harvest																																			
	Cucumber, muskmelon, summer squash, bell pepper, tomato, sweet corn	Transplant																																			
		Harvest																																			
Hot season	Eggplant, English cucumber, hot pepper, cherry tomato, okra, watermelon, ginger, turmeric	Transplant																																			
		Harvest																																			

Figure 4-2: Suggested vegetable planting calendar for Piedmont region of North Carolina.

Planting Calendar for N.C. Coastal Plains

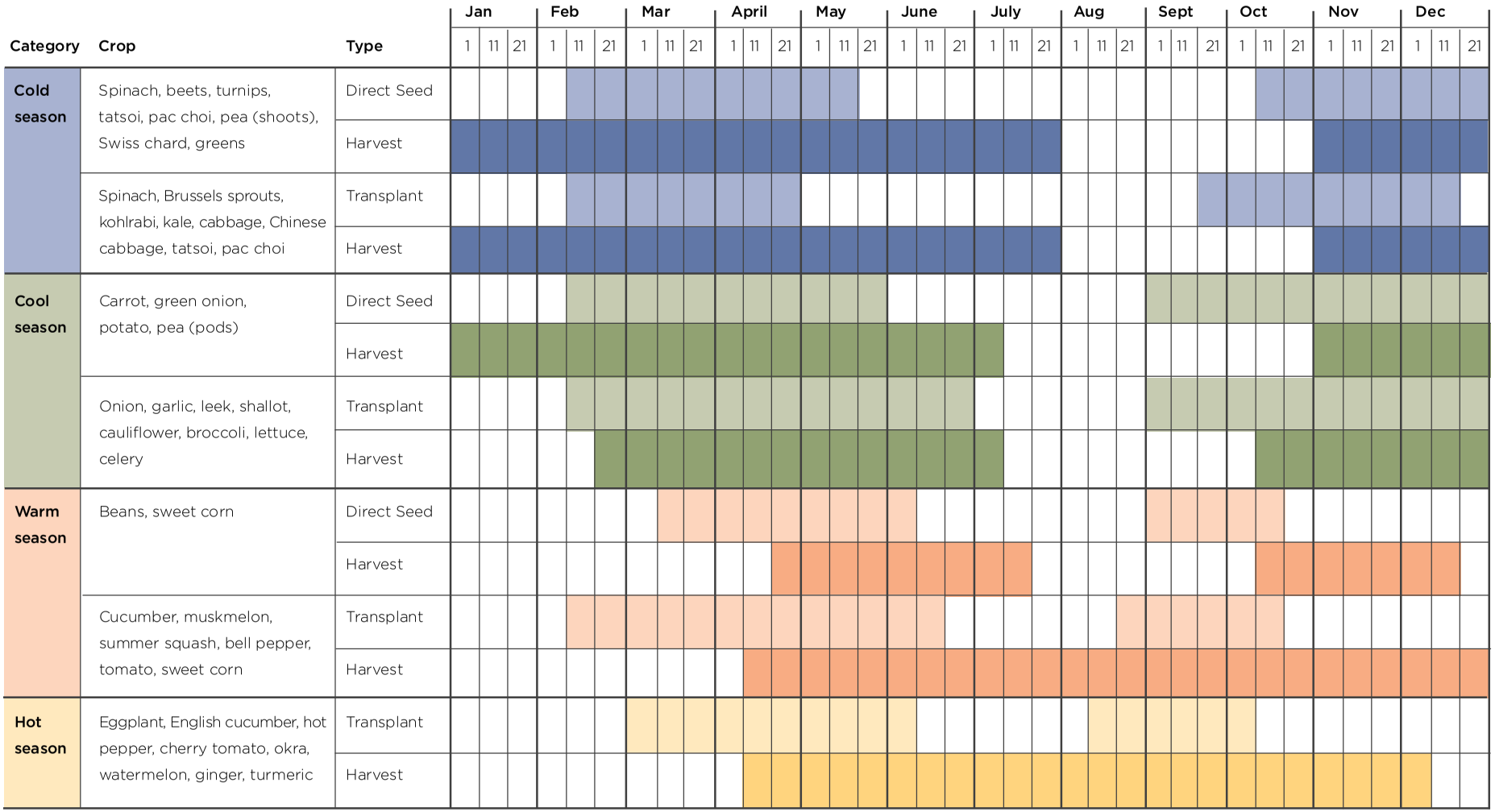


Figure 4-3: Suggested vegetable planting calendar for coastal plains of North Carolina.

Soil Health Management Strategies and Soil Preparation in High Tunnels

Healthy soil is the key to successful crop production in high tunnels. Before preparing your high tunnel soil for crop production, you need to know your soil type(s), know how to improve your soil, and how to apply pre-plant fertilizers based on soil test results.

1 KNOW YOUR SOIL TYPE

- Use the USDA Natural Resource Conservation Service Soil Survey.

2 IMPROVE SOIL HEALTH

- Grow cover crops.
- Add compost and/or manure.

3 ADD PREPLANT FERTILIZERS

- Do soil tests.
- Apply up to 40% of recommended fertilizer as preplant (compost/manure, chemical fertilizers).

4 MAKE BEDS

- Work preplant fertilizer into soil.
- Disk or till the soil.
- Make raised beds.

FIND OUT YOUR SOIL TYPE

USDA's Natural Resources Conservation Service (NRCS) has created detailed reports of our nation's land called soil surveys.

- A soil survey is a detailed report on the soils in an area.
- The soil survey has maps with soil boundaries and photos, descriptions and tables of soil properties and features.
- It is essential to know the soil types on your farm, especially where your high tunnels sit.

If you want to use a printed soil survey, you can get one from the NRCS office or from a local conservation office. You can also obtain the survey online by using the Web Soil Survey (WSS) at *https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.* Instructions on how to use the survey are available at *https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.* An instructive PowerPoint presentation is accessible at *https://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=nrcs142p2_051369&ext=ppt.*

There are four steps when using the WSS:

1. Define your Area of Interest (AOI).
2. View the soil map.
3. Explore soil data and add data of interest to your shopping cart.
4. Check out using the shopping cart. This creates your soil report(s).

If you have a question on finding your soil type(s), contact your local NRCS office or Extension office.

IMPROVE YOUR SOIL

Picture 5-1: Adding compost to a high tunnel before soil preparation.

Vegetable crops grow best in soils with slightly acidic to neutral pH. They should be well-drained loam soils with organic matter content of 3% or higher. Unfortunately, most high tunnel growers do not have this ideal soil to begin with. That means it is essential to develop a strategy to improve your soil because soil improvement is a long-term process. When designing your strategy, consider compost/manure and cover crops as long-term efforts and chemical fertilizer applications as short-term efforts.

Add compost and composted manure to your soil. You should incorporate compost or well-composted manure to your high tunnel every year. This is necessary because when you remove vegetable residues (biomass) from the high tunnel, you deplete organic matter and minerals in the high tunnel soil.

- Compost and manure improve soil physical properties and increase organic matter contents in soil.
    - o When adding manure to high tunnel soil, it is critical to watch out for a build-up of salts, as excessive salts cannot be leached by rainwater in high tunnels.
    - o Add compost and/or manure based on soil test results and the nutrient content. Nutrient content is the amount of nitrogen (N) phosphorus (P), potassium (K) and other minerals in the compost or manure.
- Up to a 1-inch depth of compost (about 135 cubic yards or close to 50 tons per acre depending on the moisture content as shown in Picture 5-1) can be added to high tunnel soil each year.
    - o Five to 10 tons of compost/acre are typical rates for compost application. This translates into adding 660 to 1,320 pounds of compost to a 30-foot by 96-foot high tunnel.
        - + To simplify your application, simply add a ton of compost to a 30-foot by 96-foot high tunnel each season.
- Till the soil to incorporate compost/manure.

Grow cover crops

When possible, you should have one season of cover crops in your crop production cycle (Pictures 5-2 and 5-3). This practice could be in summer or winter, depending on your crop schedules.

- Do not grow perennial cover crops in high tunnels unless you do not plan to grow any cash crops.

- Terminate cover crops by using a flail mower or similar equipment and incorporate them into the soil at least two weeks before planting the cash crops.

Picture 5-2: Demonstration of sunflower, mustard and soybean cover crops in a high tunnel on the N.C. A&T University Farm.

Picture 5-3: Summer cover crop sorghum-sudangrass mixed with cowpeas in a high tunnel on the N.C. A&T University Farm.

All About Cover Crops

Some people refer to cover crops as green manure, especially when the cover crop is a legume. Cover cropping involves growing, but not harvesting, an annual grass, legume, or a mixture of grass and legume. The USDA's National Organic Program recommends growing cover crops in organic systems to manage crop nutrients and soil fertility. Although cover crops might not offer a short-term financial reward, they have long-term economic benefits for farmers, including reduced fertilizer and pest control costs and improved yields through better soil quality.

Cover crops benefit cropping systems by:

- Building soil organic matter.
- Reducing soil erosion.
- Increasing nitrogen fertility.
- Suppressing weeds and pests.
- Improving soil physical properties.
- Retaining mineral nutrients.
- Conserving soil moisture.

In the climates of the southeastern U.S., high tunnels are typically used for season extension in the spring, fall and winter. In the hot summer months, it is difficult to grow anything but the most heat tolerant crops in high tunnels without shade cloth. It is also uncomfortable to work in high tunnels due to the heat. During the summer, between late spring and early fall crops, is an excellent time to incorporate a summer cover crop.

Many cover crops species are adapted to hot southern summers and perform well in high tunnels (see Table 5-1 on the next page).

If you do not plan to grow winter vegetables in high tunnels, consider planting winter cover crops in the tunnels after the fall harvest. From mid-December to late March, you can grow one season of winter cover crops such as mustards, radish, winter peas and winter rye or their mixes.

All About Cover Crops

SPECIES	TYPE AND CHARACTERISTICS	SOWING TIME
Buckwheat	Broad leaf grain. Fast growing, outcompetes weeds, pollinator and beneficial insect friendly	April - July
Cowpea	Legume. Fast growing, high biomass production, nitrogen fixation, weed suppression, drought tolerant	Mid-spring to early summer
Millet	Grass. Fast growing, high biomass production, weed suppression	Summer, soil must be at least 60° F
Mustard	Broadleaf brassica. Weed suppression, reduces soil-borne fungal pathogens and nematodes, attracts beneficial insects	Spring, summer
Soybean	Legume. High nitrogen fixation, weed suppression	Late spring, early summer
Sudangrass	Grass. Fast growing, high biomass production, nitrogen catch crop, suppresses weeds and soil pests. Need to mow frequently to manage height	Late spring, early summer when soil is at least 60° F
Sunflower	Broadleaf. Mines nutrients from the soil profile, flowers attract pollinators	Spring to early summer
Sunn Hemp	Legume. Fast growing, nitrogen fixation, high biomass production	May - July

Table 5-1. Summer cover crop species for high tunnels in North Carolina.

Know your soil's fertility status by conducting soil tests

A soil test lets you know what nutrients are in your soil and available to the crops you plan to grow. Information you can obtain from a soil test includes:

- Levels of major plant nutrients, including phosphorus, potassium, calcium, magnesium and sulfur.
- Levels of plant micronutrients, including copper, manganese and zinc.
- Levels of sodium; pH and acidity.
- Soil class.
- Percent base saturation.
- Percent humic matter or humus, the humic substances present after the biological degradation of organic matter.
- Cation exchange capacity, or the ability of soils to store one particular group of nutrients, the cations.
- Weight-to-volume ratio.

Based on crops you intend to grow, a soil test report will tell you what and how much fertilizer to add to your soil and whether you need to adjust soil pH. If you have not had your soil tested in the past, please contact your county Extension office or learn more at the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) soil testing web page: *https://www.ncagr.gov/agronomi/sthome.htm.*

Soil testing is a three-step process that involves: 1) filling out a soil test form; 2) collecting soil samples; and 3) sending the samples to the NCDA&CS for testing. Basic soil tests are free for North Carolina residents from April through Thanksgiving. Tests cost $4 per sample from Thanksgiving through March.

Adjust soil pH

Most plants grow best in slightly acidic to neutral soils with a pH of 6.2 to 7.4. North Carolina soil can be acidic so liming—adding calcium- and magnesium-rich minerals to reduce soil acidity—is a common practice. In high tunnels, however, soil can become alkaline (high pH), if you consistently add manure to it.

- To increase soil pH, add lime or its equivalent to the soil.
- To decrease soil pH, add sulfate or its equivalent to the soil (see Table 5-2).
- Correcting soil pH is a slow process; it takes a long time and a great amount of lime or sulfate to elevate or lower soil pH by one-half of a unit.

Work lime or sulfate into the top six inches of high tunnel soil before making beds. Sandy soil needs the least amount of lime or sulfate, while clay soil needs the most (Table 5-2).

Soil pH	***Pounds of lime per 100 square feet***	***Pounds of sulfate per 100 square feet***
<5.0	20	0
5.0-5.5	10	0
5.6-6.4	5	0
6.5-7.4	No need to adjust	No need to adjust
7.5-7.9	0	1 lb. sulfur or 5 lb. iron sulfate or 5 lb. aluminum sulfate
8.0-8.9	0	2 lb. sulfur or 10 lb. iron sulfate or 10 lb. aluminum sulfate

Table 5-2: Adjusting soil pH in high tunnels

Soil pH and Nutrient Availability to Crops

Soil pH describes the relative acidity or alkalinity of the soil. Soils are considered acidic if pH is less than 5, and very acidic if pH is less than 4. They are considered alkaline if pH is greater than 7.5, and very alkaline if pH is greater than 8.

Soil pH affects the availability of mineral nutrients to plants. Most plant nutrients are optimally available to plants within the 6.5-7.5 pH range (Figure 5-2). This range of pH is also optimal for plant root growth.

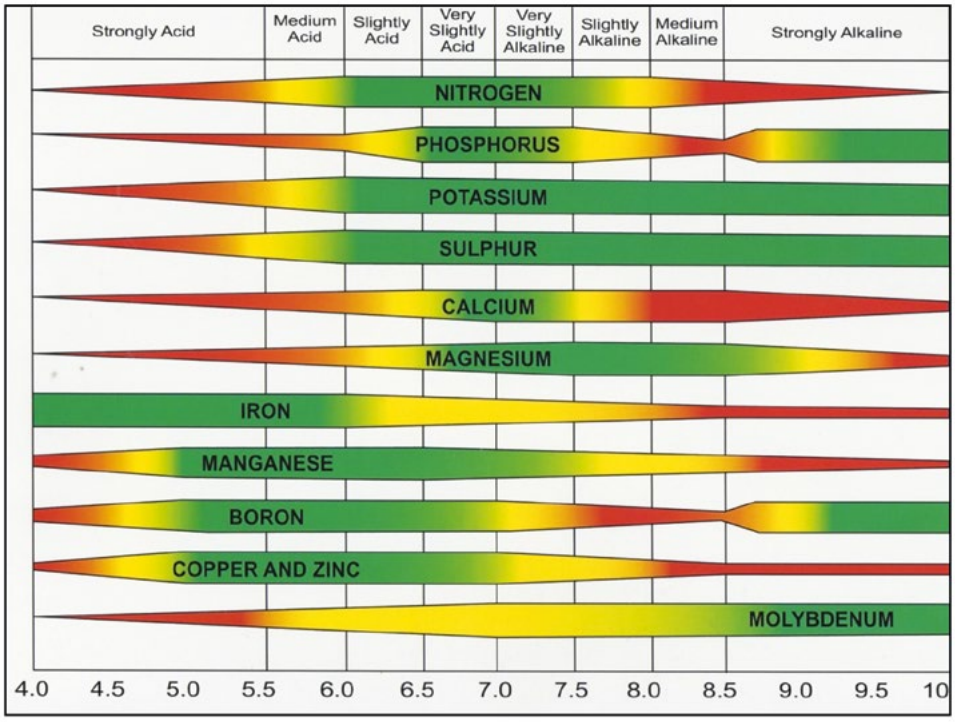


Figure 5-2: The influence of pH on the availability of plant nutrients in mineral soils. Green indicates the range of soil pH in which a mineral is available for plants to absorb.

ADD PRE-PLANT CHEMICAL FERTILIZERS (NATURAL OR SYNTHETIC) BEFORE PLANTING.

Chemical fertilizers are important to soil fertility management in high tunnels because crops in high tunnels respond to them quickly for growth and development. About 40% of the total chemical fertilizers should be added to the soil at pre-planting. The remaining 60% should be added throughout the growing season by side dressing (adding fertilizer to the sides of the plant stems) or fertigation, which delivers water soluble nutrients through drip tapes.

PREPARE HIGH TUNNEL SOIL AND MAKE RAISED OR FLAT BEDS

Depending on your high tunnel soil conditions, you may need to disc or till the soil first before applying pre-plant fertilizer (Picture 5-4). Keep in mind that the top 6-12 inches of soil are the most important to crops. Use raised beds as much as you can in high tunnel production as they have many advantages over flat beds. Raised beds are 6-12 inches in height, bare soil or covered with plastic mulch (Picture 5-5). In high tunnel production, plasticulture (plastic mulch and drip irrigation) is a common practice.

Picture 5-4: Adding pre-plant fertilizer (chemical fertilizer and compost), incorporating into soil and making raised beds.

Advantages of raised bed and plasticulture in high tunnel production

Better drainage and water saving

- Growing plants in raised beds is a logical choice with heavy, poorly drained soils.
- Raised beds permit plant roots to develop in soil held above water-logged or compacted zones. This provides a more optimum soil environment for root growth.
- As beds are built up, compost or other forms of organic matter may be easily incorporated into the soil, further improving soil structure, drainage and nutrient-holding capacity.

Earlier and higher yields

- Better root growth from improved soils leads to higher yields.
- Intensive planting in raised beds means more plants can be grown in a smaller area than with conventional row-cropping techniques.

Earlier growing season

- Better drainage speeds soil warming and allows earlier spring planting. At the 2-inch depth, temperatures are higher by 4-5° F under black mulch or 8-10° F under clear mulch.
- In wet seasons, soil dries out faster, permitting planting to proceed between rains.
- Transplanting can be two weeks earlier due to warmer soil temperatures.

Fewer diseases and problems

- Better air circulation usually results in fewer disease incidences.
- Better irrigation management means calcium deficiencies can be better managed to mitigate blossom end rot.

Cleaner product

- A mulched crop is cleaner and less susceptible to rots because mulching eliminates soil splashing on the plants.

Better in fumigation and soil solarization

- Plastic mulches increase the effectiveness of soil fumigant chemicals. Because of the impervious nature of the plastic mulch, it acts as a barrier to gasses and keeps gaseous fumigants in the soil.
- Plastic mulches, especially clear ones, are used in soil solarization to control soil pests.

Picture 5-5: Raised beds with drip irrigation with plastic mulch (left) and without plastic mulch (right) in a high tunnel.

Managing Fruiting Vegetables Such As Tomato and Cucumber

Fruiting vegetables such as tomato and cucumber are major cash crops for high tunnels. They are warm-season vegetables that cannot grow through winter in North Carolina. They are generally trellised and produce fruit continually. Practices introduced in this chapter apply to tomato, bell pepper, eggplant, English cucumber, melon and watermelon.

RAISED BEDS AND SPACING

- A 30-foot by 96-foot high tunnel is large enough for six raised beds (two rows of plants per bed) along the length of the high tunnel. These are called long beds, as shown in Figure 6-1 and Picture 6-1.
  - o Do not use crossway beds (beds along the width of the tunnel) unless you must.
  - o Use 4-foot or 5-foot black plastic mulch and 12-inch drip tape.
  - o Each row should have one line of drip tape. 6- or 8-inch drip tape is fine as well.
- The bed width should be about 2.5-3 feet on the bed top.
  - o The alleyway between beds should be 2-2.5 feet.
  - o Leave 3 feet between the end of beds to the end walls and 1-1.5 feet between the side walls and the beds, making your long beds for crop production about 90 feet long.
  - o The size of your tractor will determine the size of raised beds. Smaller tractors are ideal for high tunnel production.

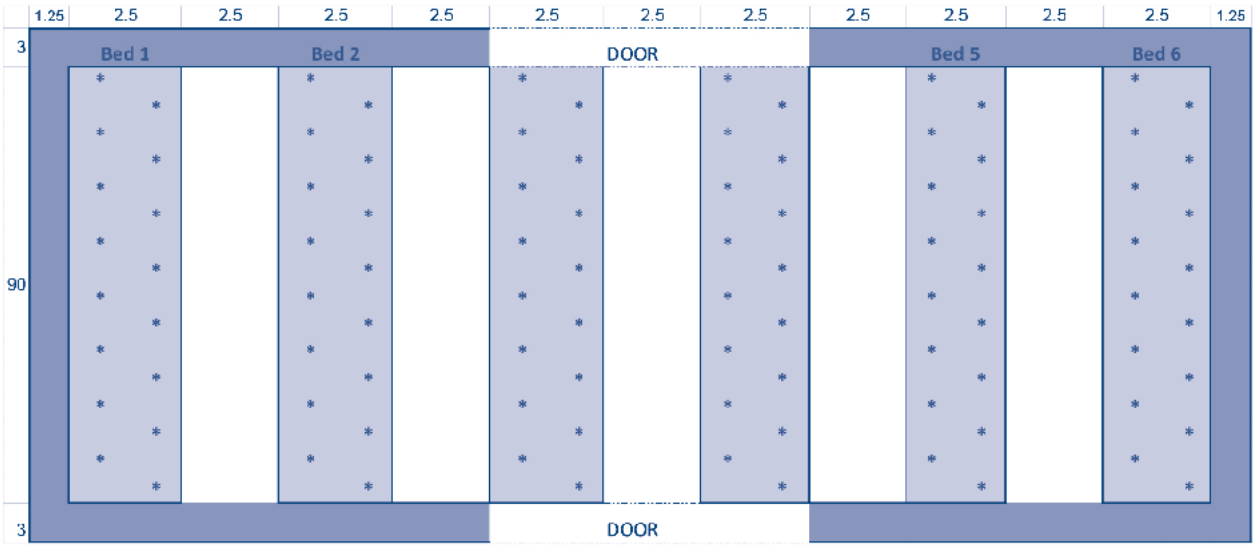


*Figure 6-1: An example of raised beds and plant spacing in a 30-foot by 96-foot high tunnel. Note: Measurements are in feet. * represents plants. Drawing is not proportional.*

Picture 6-1: An N.C. A&T University Farm high tunnel with six raised beds (plastic mulch and bare soil).

TRANSPLANTING

When transplanting, always use healthy, disease-free transplants.

- Do not break the soil/root ball when transplanting.
- Plant two rows in each bed by staggering plants (Figure 6-1).
- Use in-row spacing of 2 feet, although 1.5 feet is also acceptable depending on cultivars, trellising and training of the plants.
- Water beds thoroughly after transplanting.

TRELLISING

Trellising supports plants and leads them to grow vertically. There are many ways to trellis a commercial fruiting vegetable crop.

- Use plastic wire mesh, cattle panel or strings for cucumber vines (Picture 6-2)
- Use the Florida Weave method with tomato stakes or the Roller-Hook® system with strings (Figure 6-3).
  - o Use tomato stakes (Florida Weave) for determinate tomato, eggplant and bell pepper.
  - o Use Roller-Hook® for indeterminate tomato, cucumber, melon and watermelon.
- Set up trellises based on the structure of your high tunnel (Picture 6-4).
- Train plants to one leader if using strings or the Roller-Hook® system.

Picture 6-2. Plastic wire mesh (left, vines not pruned) and Roller-Hook® (right, vines pruned to one leader) trellises for cucumber production.

Picture 6-3. Eggplants trellised with Florida Weave (left) and watermelons with Roller-Hook® methods (right).

Picture 6-4. Braces in high tunnels are used to support wires for the Roller-Hook® trellis system (top). Anchor boards can also be added to end walls for support of trellises (bottom).

PRUNING AND TRAINING

Pruning refers to the removal of lateral buds (called suckers), and old and diseased leaves. Training is directing plant growth to have one or more dominant shoots called leaders along the trellis.

- Pruning and training help plants have balanced vegetative and reproductive (fruiting) growth, so they produce better yields for a longer time.
- Pruning and training increase light reception and improve air circulation so plants will be healthier and have fewer disease problems.
- When using the Roller-Hook® system, train plants to one leader and occasionally two leaders. All lateral buds on a leader should be pruned off.
- When using the Florida Weave system, prune off suckers up to the first fruit cluster, then leave remaining suckers unpruned.
- Prune off old leaves on trellised plants (Picture 6-5). This will stimulate new growth, increase light reception in the canopy, and decrease incidences of foliar disease.

Picture 6-5. Old leaves of cucumber vines are pruned off and vines are dropped after pruning (left). Older, lower leaves of eggplant and tomato plants that should have been pruned off (right).

IRRIGATION AND FERTIGATION

Irrigation is not optional in high tunnel production because the plastic cover keeps rain out. Irrigation methods in high tunnels include sprinkler and trickle irrigation.

- To use trickle irrigation, place drip tapes on top of bare soil raised beds or bury them under the plastic mulch if using mulch.
  - o A trickle irrigation system uses 30-50% less water than a sprinkler system, and the water is rationed to the plants as they need it.
  - o This system also enables growers to water only the desired plants, not the row alleys.

Vegetables require an adequate supply of moisture throughout their entire growth. Generally, 1-1.5 inches of water is required each week for fruiting vegetables, depending on the crop, its growth age, soil type and weather conditions.

- Make sure to know your crops' critical times of irrigation (Table 6-1).
- Do not apply more than a quarter inch (0.25) of water at a time with drip irrigation systems, especially when conducting fertigation or chemigation.
    - o Applying more than a quarter inch of water at a time will move water, as well as the nutrients and pesticides it carries, below the plant's root zone and beyond the reach of the plant's roots.

Crop	***Critical Period***
Snap Beans	Pod enlargement
Sweet Corn	Silking and tasseling, ear development
Cucumber, Melon, Eggplant, Pepper	Flowering and fruit development
Summer Squash	Bud development and flowering
Tomato	Early flowering, fruit set and enlargement

Table 6-1: Critical periods of water needs for fruiting vegetable crops in high tunnels.

Refer to Table 6-2 to determine the maximum recommended irrigation time needed when using drip irrigation systems. Irrigation periods are based on the flow rate of the drip tapes. Also, keep in mind that the texture of the soil affects the time needed for drip irrigation.

Drip tape flow rate		***Mulched bed width (ft)***				
gph/100ft	***gpm/100ft***	***2.0***	***2.5***	***3.0***	***3.5***	***4.0***
8	0.13	15.5	19.5	23.5	27.0	31.0
10	0.17	12.5	16.5	18.5	22.0	25.0
12	0.20	10.5	13.0	15.5	18.0	21.0
16	0.27	8.0	10.0	11.5	13.5	15.5
18	0.30	7.0	8.5	10.5	12.0	14.0
20	0.33	6.0	8.0	9.5	11.0	12.5
24	0.40	5.0	6.5	8.0	9.0	10.5
30	0.50	4.0	5.0	6.0	7.0	8.5
36	0.60	3.5	4.5	5.0	6.0	7.0
40	0.67	3.0	4.0	4.5	5.5	6.0
42	0.70	3.0	4.0	4.5	5.0	6.0
48	0.80	2.5	3.0	4.0	4.5	5.0
50	0.83	2.5	3.0	4.0	4.5	5.0
54	0.90	2.5	3.0	3.5	4.0	4.5
60	1.00	2.0	2.5	3.0	3.5	4.0

Table 6-2: Hours needed to apply 1 inch of water to the mulched area.

SOIL TYPES AND THE IRRIGATION STRATEGY

Water is absorbed and moves slowly through clay soils, but once wet, clay retains significant amounts of moisture. On the contrary, water is absorbed and moves quickly through sandy soils, but they retain moisture poorly (Figure 6-2).

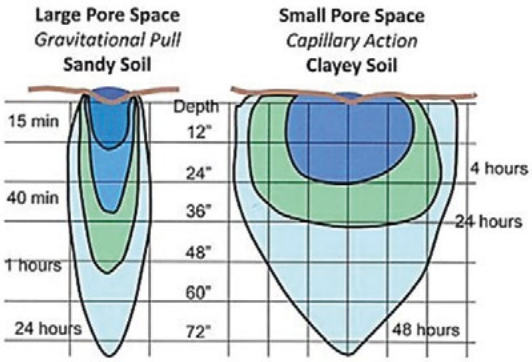


Figure 6-2: Depth of water absorption and the time it takes in sandy soil and clay soil.

With this in mind, add water slowly (long period) and less frequently with clay soils, but quickly (short period) and more frequently with sandy soils. Water applied quickly to clay soil has a tendency to run off rather than move into the soil. Water applied to sandy soil can move beyond the root zone, leach out and become unavailable to plants. For efficient water use and depending on temperatures, high tunnels with sandy soils may need daily irrigation for a short period while clay soils may need irrigation every two or three days for a longer period.

If you use surface water in cold months, for example from a pond, make sure to flush residue water in your pipes (unless the pipes are buried) to avoid a quick drop in soil temperature due to the cold water.

PEST MANAGEMENT

Pests inside high tunnels include insects, diseases, weeds and other critters. Traditionally, pest control involves the routine application of pesticides. In high tunnels, however, you should use integrated pest management (IPM) practices that center around prevention and minimize the use of synthetic pesticides.

What is Integrated Pest Management?

IPM is "the coordinated use of pest and environmental information with available pest control methods to prevent unacceptable levels of pest damage by the most economical means, and with the least possible hazard to people, property, and the environment."

There are four steps in IPM:

1. Accurately identify the pest (problems) and monitor progress: It is most important to know what pest you are dealing with. The Plant Disease and Insect Clinic can help with identification *(https://projects.ncsu.edu/cals/plantpath/extension/clinic/)*.

2. Set up a control threshold: Some levels of pest damage are acceptable. The control or action threshold is the point at which pest population or environmental conditions indicate that the pest control action must be taken.

3. Prevention and exclusion: The first line of control will be using cultural methods that prevent pests from becoming a threat.

4. Control: Once the threshold is met, consider the following methods: mechanical and biological control (low risk), insecticidal soap and botanical pesticides (medium risk) and synthetic pesticides (high risk).

DISEASE

For a disease to occur, all three of the factors below (the pathogen, susceptible host, and a favorable environment for disease development) need to be present at the same time. (Figure 6-3).

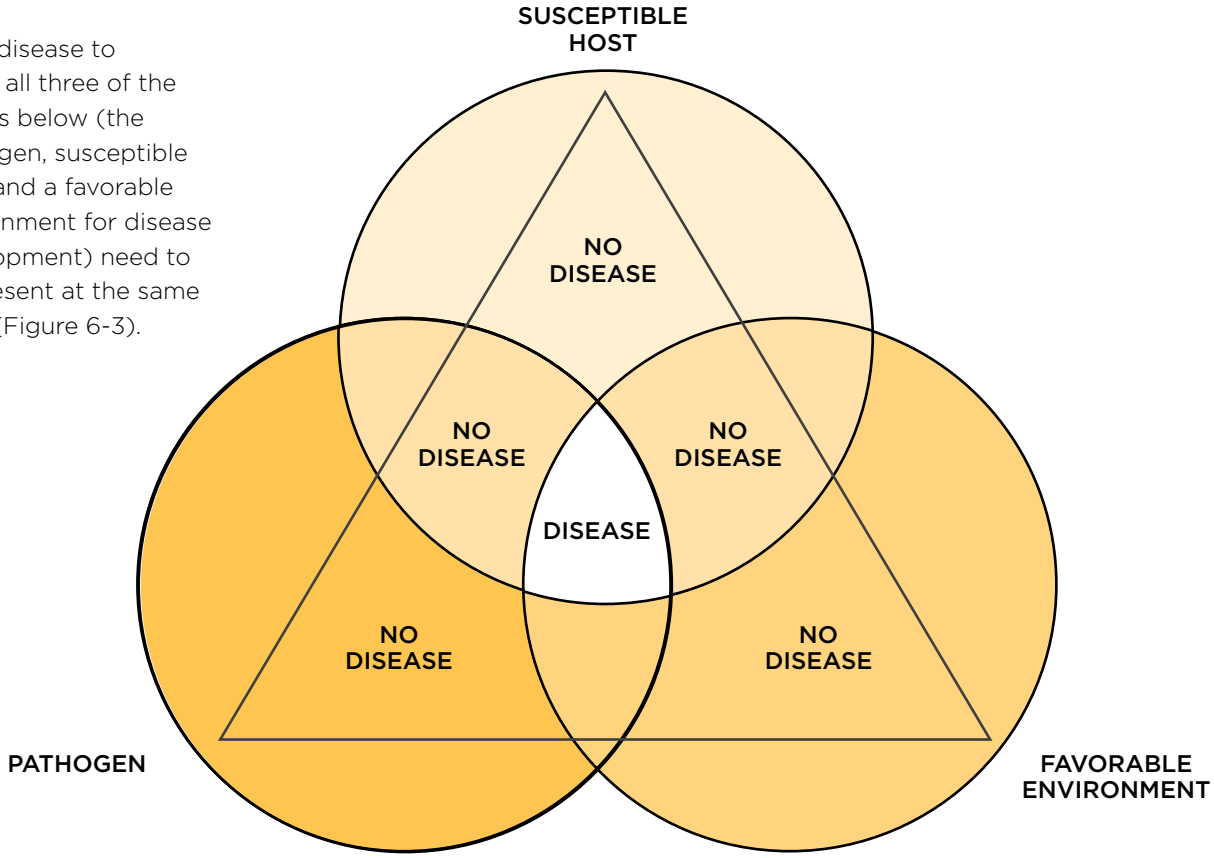


Figure 6-3: The disease triangle—disease occurs when all three factors co-exist.

As a general rule, consider the following practices to control diseases in high tunnels. The focus should always be on disease prevention.

- Use disease-resistant cultivars. Use cultivars that fit your needs and that have codes with more letters and numbers. These are disease resistant or tolerant codes.

- Ventilate high tunnels in a timely manner to minimize the relative humidity and hours of leaf wetness.

  o Some diseases, such as those spread by rain splash, will be less common in high tunnels, while others that thrive in dry (powdery mildew) or humid environments (downy mildew), may be more common in tunnels.

- Use grafted fruiting vegetables if you have soil-borne disease problems.

  o Other soil-borne disease control methods include proper crop rotation, bio-fumigation and solarization.

- Use disease forecast tools and news about pest outbreaks provided by Cooperative Extension and act accordingly. For example, use preventative sprays if an outbreak of cucumber downy mildew or tomato late blight occurs in your county.

  o This is especially important for avoiding air-transmitted diseases such as tomato late blight and cucumber downy mildew.

- Prune off old and diseased leaves.

- Apply fungicides as the last resort.

SOIL SOLARIZATION IN HIGH TUNNELS

In summer months, the temperatures inside high tunnels can be too high for some fruiting vegetables to remain productive. There is also no price advantage to high tunnel growing in the summer compared to field grown vegetables. This time—before your fall vegetable plantings—can be a good time for soil solarization. Soil solarization can kill many fungal pathogens, nematodes and weed seeds. The steps for solarization are:

Prepare soil. All plant material should be removed from the soil for the soil to be solarized. Move everything out of the high tunnel. Prepare soil as you would for bed formation.

Irrigate soil. Wet the soil to at least 12 inches in depth.

Put on plastic. Place clear plastic on the soil after irrigation. The thinner the plastic, the better. Plastic of 1-2 mils should work well, or use 6-mil old plastic. The plastic should be placed in close contact with the soil.

Reach high temperatures. Target the soil temperature in the top six inches to 110-125º F. Insert at least one soil thermometer to monitor the soil temperature. Close the high tunnel to raise the temperature. Check items that cannot be moved, such as fertilizer injectors and auto-ventilation controllers, and ensure the high temperatures will not damage them.

Solarize for a reasonable length of time. The hottest months, July and August, are great for solarization. Solarize the soil for three to four weeks. The higher the temperatures achieved in the soil, the less time is required.

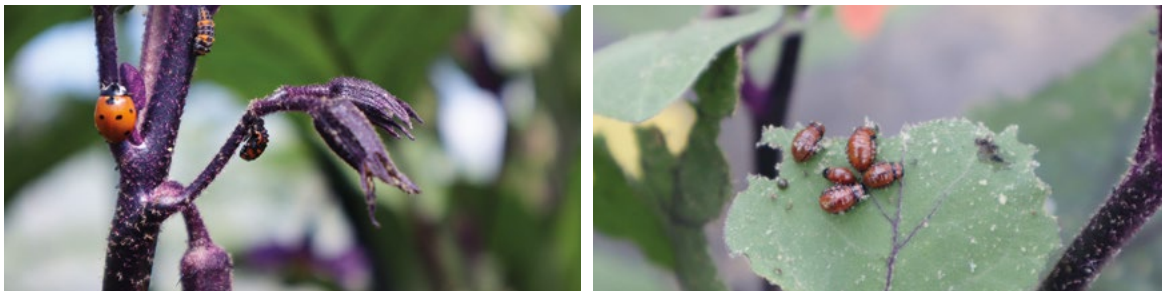
INSECT PESTS AND SPIDER MITES

Commonly seen insect pests in high tunnels include fruit worms (Picture 6-6); cut worms, which cause the most damage right after transplanting; cucumber beetles (Picture 6-7); Colorado potato beetles (Picture 6-8); and aphids (Picture 6-9). Insect pests are not significant problems in high tunnels if scouting is done regularly for timely control.

- Use insect screens on side walls if possible. This is a must for organic cucumbers.
- Use Bt-products to control fruit worms. These products contain *Bacillus thuringiensis*, a microbe naturally found in soil that is toxic to insect larvae.
- Use insecticidal soap, horticultural oil or botanical pesticides such as neem oil to control aphids.
- Use beneficial bugs. Check out Koppert for options (*https://www.koppertus.com/*).
    - o Release beneficial bugs such as lady beetles (Picture 6-8) to control aphids.
- Spider mites can develop quickly in the warm, dry and sometimes dusty high tunnel environment. To control, release predator mites such as *Phytoseiulus persimilis*. If the predator mites become less effective, use miticides.

Picture 6-6: Tomato fruit worms in young (left) and mature (right) fruit.

Picture 6-7: Striped cucumber beetles cause physical damage (left) and transmit bacterial wilt disease (right).



Picture 6-8. Beneficial adult ladybug and larvae (left), and Colorado potato beetles (right), a pest, on eggplants.

Picture 6-9: Severe aphid infestations on melon and watermelon leaves.

WEEDS

With the use of plastic mulch (Picture 6-10), weeds should not be a serious problem in high tunnels.

- Cultivate the edges of raised beds.
- Hand pick weeds growing out of the planting holes in a timely manner.

Figure 6-10: A side-by-side comparison of weed control in a plastic mulched bed (left) and a bare-soil bed (right).

POLLINATION

- Tomato, pepper and eggplant are self-pollinating species so pollination is usually not an issue.
    - o In cold months, when temperatures are low and relative humidity is high, poor pollination can occur. Increased ventilation and "shaking" the trellis can usually take care of the problem.
- When growing cucurbits such as cucumber and zucchini, choose seedless cultivars if at all possible.
    - o For seedless cucumber and zucchini, pollination will produce misshapen fruit and should be avoided.
    - o For regular cucumber and zucchini, bumble bees are excellent commercially available pollinators.
- Melon and watermelon need pollination to produce fruit.
    - o Open up the side walls (do not use insect screens) or windows on the end walls if you can, so pollinators can get inside the high tunnel.
    - o If desired, purchase and release bumblebees (*https://www.koppertus.com/natupol-excel-start-up/*).

Managing Cold-Hardy Vegetables

Cold-hardy vegetables include cool-season and cold-season vegetables. In an open field, cold-season vegetables can survive winter without additional frost protection but they will not grow much; however, cool-season vegetables cannot survive winter without severe cold damage.

Inside a high tunnel, both cool-season and cold-season vegetables will grow and mature in winter with additional protections such as row covers. Cold-hardy vegetable production takes place in fall, spring or winter, but usually not in summer.

SPECIES AND CULTIVARS

There are many cold-hardy vegetable species (Picture 7-1). Below are some examples, although this is not an exhaustive list:

- Salad greens: various types of lettuces.
- Leafy greens: served raw or cooked.
  - o Brassica salad mixes (mustards)
  - o Asian greens (bok choi, tatsoi, tsai tai, etc.)
  - o Swiss chard
  - o Collards
  - o Kale
  - o Spinach: baby leaf and bunch spinach
- Root vegetables: carrot, beet, radish, turnip.
- Alliums: scallions, green and bulb onions, green or clove garlic.
- Legumes: pea shoots and pods, fava beans.
- Others: cabbage, Napa (Chinese) cabbage, broccoli (for leaves and/or crowns), cauliflower, celery and kohlrabi. These grow well in high tunnels but need a long season to mature (an exception is broccoli grown for leaves).

Picture 7-1: Over-winter vegetables at N.C. A&T University Farm.

WHEN GROWING COLD-HARDY VEGETABLES, CONSIDER THE FOLLOWING:

- Choose species based on your market's needs, focusing on fast-growing species, especially for winter harvests.
  - o Use bolt-resistant cultivars.
  - o Use highly frost-tolerant cultivars.
  - o Use cultivars of different maturities.
- Determine sowing and transplanting dates based on your reasonable target harvest dates and work backwards.
  - o Practice secession planting, which means planting vegetables with different maturation dates, for continuous harvests.
- Use transplants as much as you can, except for cut-and-come-again lettuce and green mixes, root vegetables (with beets being an exception), and peas.
  - o Use black plastic mulch with transplanted vegetables.
- Use raised beds and drip irrigation.
  - o Use 30-inch wide raised beds with three or four rows in each bed. Refer to Chapter 6 of this field guide for more information on raised beds in high tunnels.
  - o Choose a drip tape based on plant spacing. The emitter spacing of your drip tape could be 6 inches, 8 inches or 12 inches. Plant transplants adjacent to drip emitters.
- Use reasonably narrow spacing in fall and winter but regular spacing in spring.
  - o Use 8-12-inch spacing for winter production.
- Practice intercropping.
- Ignore the 10-hour day length guideline, which says that most plants need at least 10 hours of daylight to grow. Cold-hardy vegetables will grow and be harvestable in high tunnels when the day length is less than 10 hours.

FERTILITY MANAGEMENT AND IRRIGATION

Fertility. Pay close attention to pre-planting fertilization. Based on soil test results, incorporate all composts and chemical fertilizers when making raised beds for fast-growing species. However, incorporate only 40% of chemical fertilizers for long-season species.

- Compost and composted manures help raise soil temperatures.

Irrigation. In general, one inch or less of water each week is plenty for cold-hardy vegetables.

- Avoid using sprinklers.
- Water in mid-afternoon, when temperatures are usually the highest.
  - o If using surface water in winter, flush out residual water in the irrigation pipes unless you are sure that the water has been warmed up by sunlight.

TEMPERATURE MANAGEMENT

Keeping a warm environment is essential for cold-hardy vegetables, especially during winter. Manage temperatures based on the need of the species grown. Try to keep the temperatures in the optimal range and definitely above the lowest temperature that a species needs to grow—not just survive.

- Try to maintain temperatures of 60-68° F.
  - o Start to ventilate at 65-68° F depending on weather.
  - o Refer to Table 7-1 for the temperature requirements of selected species.
  - o For over-winter production, winterize your high tunnel to minimize leaks of the trapped warm air.
- Keep low temperatures above 40° F for most species.
- Apply row covers when the field temperature forecast is less than 40° F at night.
  - o Lift row covers in the morning.
  - o Use the row covers for frost protection, not for keeping out insects. Covers should be 1.2 ounces or more per square yard.
  - o Use one or two pieces of row covers per tunnel, depending on the width of your tunnel. Row covers come with different widths, for example, 15, 26 or 30 feet.
  - o You can place row covers directly over your crops or over support hoops (Picture 7-2).
- Maintain soil temperatures above 40° F; the higher the better.
  - o The temperature of irrigation water significantly affects soil temperature.
  - o Soil temperatures increase very slowly.

Crop	***GDD Base (°F)***	***Monthly Temperature (°F) Range for Growth***		
		Minimum	***Optimal***	***Maximum***
Beets, Broccoli, Cabbage, Collards, Kale	40	40	60-65	75
Carrots	38	45	60-65	75
Lettuce	40	35	60-65	75
Onions	35	35	55-75	85
Potatoes, Peas	40	40	60-65	75
Spinach	35	35	60-65	75

Table 7-1: The base temperatures for growing degree days (GDD) and the approximate monthly temperatures for best growth and quality of selected cold-hardy vegetables.


Picture 7-2: Row covers for added frost protection placed directly over crops (left) and placed over supporting hoops (right).

PEST MANAGEMENT

Cold-hardy vegetables can experience minor pest problems in high tunnels.

- Although not usually a threat, aphids (Picture 7-3) can spread quickly if not controlled quickly. Scout weekly and spot-treat with insecticidal soaps once the aphids appear.

- Lettuce drop (Picture 7-4), caused by fungal pathogens *Sclerotinia sclerotiorum* and *Sclerotinia minor*, can occur spottily in cool and moist conditions inside a high tunnel. While spraying fungicides every two weeks can prevent lettuce drop, cultural management is preferred in high tunnels. This includes using disease resistant/tolerant cultivars, plastic mulch and drip irrigation, timely ventilation, and lifting of row covers during the daytime.

  o If a plant is infected, remove the plant residue from the high tunnel to avoid spreading the disease.

  o The disease is soil-born. It will be a problem for seasons to come if there are a lot of incidences in the high tunnel.

Picture 7-3: Aphids on an overwinter mini-head lettuce at N.C. A&T University Farm.

Picture 7-4: Lettuce drop caused by Sclerotinia sclerotiorum *and* Sclerotinia minor *on overwinter lettuce.*

HARVEST

Most cold-hardy vegetables can tolerate late or early harvests. This adds great flexibility to your market opportunities.

- You can allow plants to grow to a harvestable size for winter production and keep harvesting throughout winter. Your high tunnel serves as a large living refrigerator.

- Cold-hardy vegetable crops can go through the freezing-thawing process without cold damage, but do NOT harvest when leaves are frozen.

- Harvest cut-and-come-back-again crops about once a month.

  o Without adding more compost or chemical fertilizer, you can harvest about three times.

- Multi-harvest crops such as collard greens, kale and Swiss chard (Picture 7-5) can be harvested every two to three weeks, depending on the season.

- One-time harvest crops such as bok choi and mini-head lettuce can be harvested before reaching full size.

Picture 7-5: Swiss chard ready to harvest (top) and after harvest (bottom) at the N.C. A&T University Farm.

CHAPTER 8

Management and Maintenance of High Tunnels

High tunnel management and maintenance strategies depend on your high tunnel structure, crops and growing seasons.

MANAGING TEMPERATURE AND HUMIDITY

Ventilation is a process of exchanging warm/damp air inside your high tunnel with cool/fresh air from outside. The ventilating process removes excessive heat from high tunnels through a pressure difference created by wind and temperature gradients. In a well-designed high tunnel, a wind speed of two to three miles per hour can provide 80% or more of needed ventilation.

Air movement created by the ventilation process is fundamental to the pollination of wind-pollinated crops such as strawberries and helps self-pollinating crops such as tomatoes. Ventilation also brings in CO^2 that can be quickly absorbed by your crops on a sunny day.

In a high tunnel, ventilation is used to manage air temperature and humidity. It is typically done by opening and closing side curtains and doors on end walls, as well as windows on end walls and ridge vents if your high tunnel is equipped with those.

Ventilation through side curtains and doors

- There are two types of side curtains: the roll-up curtain and the drop-down curtain (Picture 8-1).
- For winter production and warm season production, choose drop-down curtains. These allow warm air to vent out at the top of side walls and keeps your crops from having direct contact with cold air.
- Doors can also be opened for ventilation.

Picture 8-1: High tunnels with roll-up (left) or drop-down (right) curtains.

Ventilation through windows on end walls and ridge vents

- When the temperature goes up, warm and moist air rises.
    - o If a high tunnel has a ridge vent or window, ventilate through them first (Picture 8-2).
        - + This is especially important for over-winter production because it will keep the high tunnel warm and avoid abrupt temperature changes.
    - o Adjustable wax cylinder actuators installed on high tunnel end walls automatically open for ventilation when the temperature rises. They are excellent additions to your high tunnel.
- You can also install exhaust fans for forced air exchange, as you do in a greenhouse.

Picture 8-2: High tunnels with ridge vents. Top shows the Zimmerman brand and bottom shows a ridge vent by the Rimol Greenhouse Systems.

Ventilating automatically

- Ventilation can be motorized (Picture 8-3), which is usually controlled by temperatures inside the high tunnel. A temperature sensor sends readings to the control box, which sends signals to the motor(s), to open or close the curtains as necessary.

- Automated side walls can be a big help for growers who cannot monitor the tunnel all day long. If the morning starts out cold and cloudy, but later turns clear, the high tunnel can experience dramatic temperature swings. If side walls are left up (closed), heat stress can negatively impact crops.

- If possible, use a controller that regulates curtain openings and closings by both wind speed and temperature (Picture 8-4).

Figure 8-3: Temperature controlled automatic ventilation systems used on high tunnels at the N.C. A&T University Farm. In the top photo, one motor controls both curtains; in the bottom photos, each curtain is controlled by one motor.

Picture 8-4: A wind and temperature controlled automatic ventilation system at an N.C. A&T University Farm high tunnel. Wind speeds that exceed the set-up threshold, for example 25 miles/ hour, will override the temperature control thus protecting the plastic cover.

MANAGING MOISTURE IN HIGH TUNNELS

- Standing water may appear inside a high tunnel after heavy rains (Picture 8-5). Drain or use a siphon pump or wet/dry shop vacuum (for a small amount of standing water) to remove excess water, followed by intensive ventilation to reduce moisture inside the high tunnel.
  - o If drainage is consistently an issue, a French drain may be needed around the perimeter of the tunnel to allow water to move away.
- If using sprinklers to reduce temperatures in summer for cool season crop production such as summer lettuce, make sure plant leaves dry completely before dusk.

Figure 8-5: Water that has entered a high tunnel after a heavy rain.

MANAGING TEMPERATURES BASED ON THE CROPS YOU GROW

Vegetable species vary in their temperature requirements for optimal growth. Table 8.1 shows the temperature requirements for some vegetable species. The general recommendations for temperature and humidity control through ventilation are:

- For cool season vegetables, the optimal temperature is 60-70° F. Start to vent the high tunnel when the temperature reaches 68° F.
- For warm season vegetables, the optimal temperature is 68-85° F. Start to vent the high tunnel when the temperature reaches about 85° F.
- For overwinter production, do not keep high tunnels closed all the time, even during cloudy/overcast, rainy, or extremely cold days. Ventilate for at least 30 minutes in the mid-afternoon when temperatures are relatively high.
- From late fall to early spring, close high tunnels before sunset to keep more heat in the tunnels.
- In summer, keep side curtains and doors open except in very windy weather. Also, use shade cloth on high tunnels to reduce temperatures and excessive sunlight if desired.

Crop	***Minimum***	***Optimal***	***Maximum***
Onions	35	55-75	78
Spinach	35	60-65	77
Carrots	45	60-72	77
Strawberries	40	65-75	80
Beets, Broccoli, Cabbage, Collards	40	60-65	77
Lettuce	35	60-65	80
Potatoes, Peas	40	60-65	77
Snap Beans	60	65-75	86
Peppers	60	78-82	86
Eggplant	60	70-77	95
Tomatoes	50	70-75	95
Cucumbers	60	65-75	90
Summer squash	60	65-75	86
Melons	60	65-75	89
Watermelons	60	77-89	95

Table 8.1: Temperatures (°F) for optimal growth of selected high tunnel crops.

HIGH TUNNEL WINTERIZATION AND INSULATION

Heat can escape quickly if a high tunnel is not sealed reasonably well. It is essential to seal high tunnels for winter production.

- Mound soils around the bottom of end walls and side walls.
- Patch up damage, such as holes and cracks, on plastic covers, side walls and end walls.
- Add an extra layer of greenhouse fabric inside the door and side curtains (Picture 8-6 and 8-7).
- High tunnels with inflated double-layer plastic covers insulate better than high tunnels with a single plastic cover.

Picture 8-6: An extra layer of side wall fabric adds insulation to a high tunnel in winter.

Picture 8-7: Extra plastic added to the end wall seals the gaps that leak warm air.

MANAGING SOIL TEMPERATURES

- For warm season crops, the minimum soil temperature should not be below 50° F.
- For cool season vegetables, the minimum soil temperature should not be below 40° F.
- The temperature of irrigation water greatly influences high tunnel soil temperatures.
- For winter production, when consumption of water by crops is relatively low, having water stored inside your high tunnel is helpful.
    - o Irrigation should occur in the early afternoon on sunny days.

MANAGING LIGHT

The amount of light received by a high tunnel is closely related to plant growth and development, as well as to maintaining a reasonable temperature in the tunnel.

- Wash high tunnel plastic before the growing season in fall and again in early spring, especially if your high tunnel resides in a dusty area.
    - o Dirty plastic can actually lead to 30% or more shading in a high tunnel if not cleaned.
- In cold months, allow as much light to enter the high tunnel as possible.
- In summer, excessive light may be harmful to crops. Consider using shade cloth and sprinklers.
    - o The shade cloth should not exceed 30% shade.
    - o Apply shade cloth over the plastic (the most common practice), or inside a high tunnel (Picture 8-8).
    - o Using low tunnel structures inside the high tunnel to support shade cloth is another option. However, it is more expensive and only suitable for crops with short growing times.

Picture 8-8: Put shade cloth on top of a high tunnel (left) and inside a high tunnel structure (right) for summer production.

MANAGING WIND

Utilizing winds in high tunnels is necessary for temperature and humidity control. They are also important for disease management and pollination. However, winds of more than 25 miles per hour can tear off the plastic cover if a high tunnel is open (Picture 8-9).

Picture 8-9: Plastic covers torn by winds.

Wind management starts with high tunnel site selection. The prevailing wind should be perpendicular to the side wall. In windy areas, design and development of a windbreak is critical.

When installing the plastic cover, pull the plastic tight. If possible, install straps to hold the plastic tight (Picture 8-10).

Picture 8-10: Straps installed over a high tunnel to hold the plastic cover tight.

When strong winds are forecast, close the windward side of your high tunnel or close the entire tunnel until the wind diminishes.

For better disease control, circulating fans can be installed inside your high tunnel to improve air circulation when the tunnel is closed.

MANAGING WEATHER DISASTERS

Heavy snow, ice, rain and tornadoes are headaches for high tunnel production. In these extreme situations, cutting the plastic covers may be necessary to avoid destruction of the high tunnel.

- Remove the plastic cover before winter if you do not use the high tunnel for winter production.

- Use emergent heating inside high tunnels to mitigate ice build-up on the roof.
    - o Be careful with the exhaust gas that may hurt your crops.

- High tunnels cannot survive a tornado. When a tornado watch is issued, think about your safety first. If there is time, close your high tunnels entirely (and hope for the best).
    - o Extreme windstorms can destroy high tunnels (Picture 8-11). In rare cases, you may save the structure by cutting the plastic cover.

Picture 8-11: A high tunnel destroyed by a powerful windstorm. Photo credit: Dr. Tim Coolong.

MANAGING SNOW

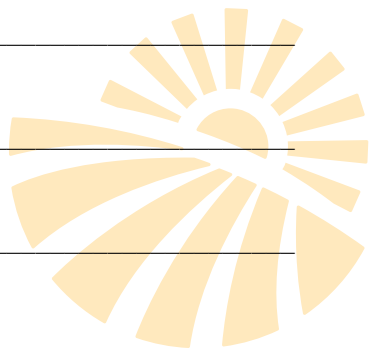
Snow is common in Hardiness Zones 5 and 6 but rare in hardiness zones 8 and 9. In Hardiness Zone 7, heavy snow is possible. If your farm is in Zones 5 to 7, consider purchasing sturdier high tunnels. When heavy snowfall is in the forecast, you should be prepared for busy days and nights. Use the following procedure to remove snow. These steps are not listed in any particular order and will depend on how much snowfall you receive and the overall weather.

- Wipe off snow from outside of high tunnels. Pull snow between bows, not over the bows, to minimize damage to the plastic cover.
- Knock out snow from between bows inside the tunnel. Start with snow closest to the side walls.
- Shovel the snow piled against the side walls.
  - o Too much snow against the side walls can damage the side curtains.
  - o This is especially critical for roll-up curtains. Drop-down curtains work better in heavy snow (Picture 8-12).
- Do not use tools that can punch holes in the plastic cover. Often, you can make tools yourself (Picture 8-13).

Picture 8-12: Snow piled up along the side walls prevents ventilation with a roll-up curtain (left), but not with a drop-down curtain (right).

Picture 8-13: Some tools used for snow removal at the N.C. A&T University Farm.

Notes:



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