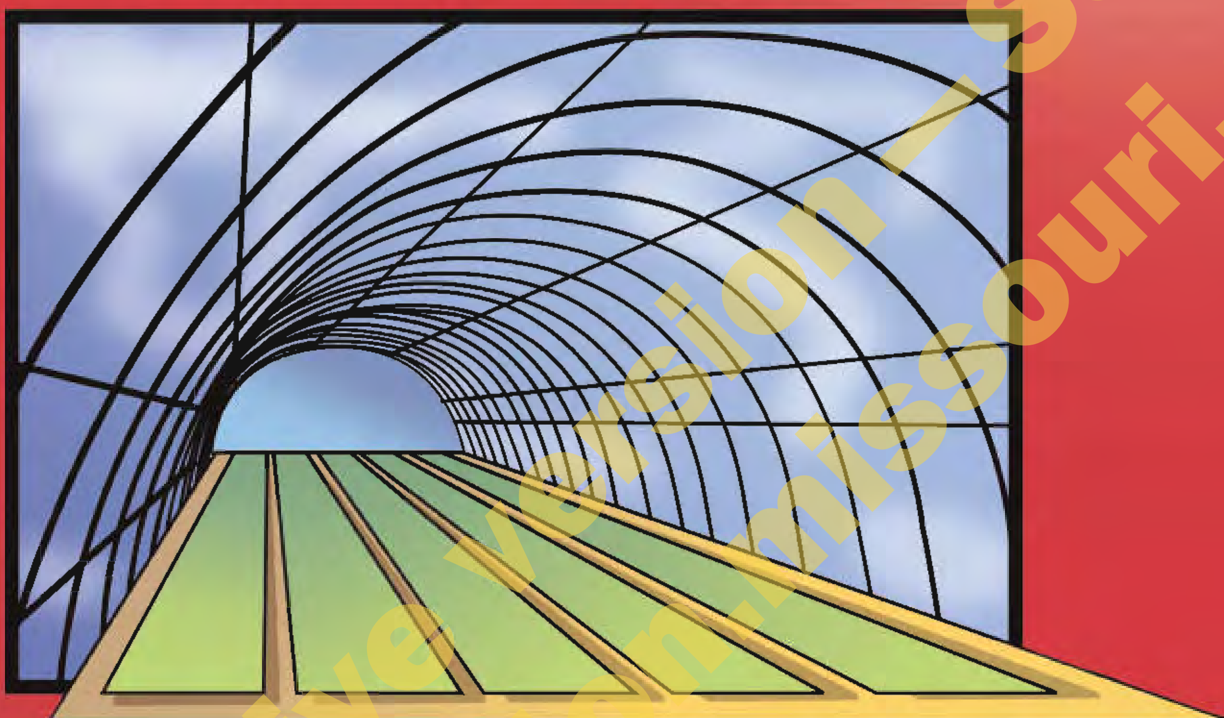
High Tunnel Tomato Production



University of Missouri Extension

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Frequently Asked Questions About High Tunnels

What is a high tunnel?

A high tunnel is a solar-heated, plastic-covered greenhouse with no electrical or automated ventilation. It can be used to extend the crop production season for many horticultural crops. Crops that are produced within high tunnels are grown in the ground with drip irrigation.

Where can I purchase a high tunnel?

There are several manufacturers of high tunnels. See the Appendix for a list of high tunnel manufacturers.

How much does a high tunnel cost?

High tunnels can be built at a cost of about \$0.75 to \$1.50 per square foot. This includes the frame structure and the plastic cover. As a rule of thumb, you should expect to pay at least an additional 25 percent for end wall lumber, site preparation, water lines and other accessories.

What are the typical dimensions of a high tunnel?

Dimensions of a commercial high tunnel range from 10 to 30 feet wide by 9 to 12 feet high by 96 to 100 feet long.

Where should I place a high tunnel on my farm?

A high tunnel should be placed on a level, well-drained, accessible site. High tunnels can be moveable, but if you wish to have a stationary unit, you will need to amend the soil each season or year with compost or other organic sources to maintain soil quality and fertility.

When can I plant vegetables in a high tunnel?

Placing a high tunnel on your farm is roughly equivalent to raising the average annual air temperatures in your area by 10–15 degrees F. Therefore, you can schedule planting based on field planting dates in the USDA hardiness zone directly south of your farm. See inside back cover for zone map.

Should I grow vegetables in a greenhouse or a high tunnel?

Input costs for greenhouse vegetable production are significantly higher than those for high tunnel vegetable production. Greenhouse establishment costs approximate \$6 per square foot, almost five times the cost of a high tunnel.

Do I need a building permit for my high tunnel?

Generally speaking, high tunnels are considered to be nonpermanent structures. However, you may need to check with your local zoning regulations.

What is the optimal orientation for a high tunnel?

When orienting a high tunnel, in contrast to a greenhouse, sunlight is less important than good ventilation. A high tunnel should be oriented in a direction that is perpendicular to the prevailing winds on your farm. Remember, all ventilation is manual, so you depend on the wind to ventilate your house.

Generally, for locations south of 40 degrees north latitude (central Illinois, northern Missouri, southern Nebraska), high tunnels should be oriented north–south. This orientation maximizes light interception and is perpendicular to the prevailing westerly winds.

Should I use a single or double layer of plastic for my high tunnel?

A double layer of plastic will almost double the insulation properties of the high tunnel. However, adding another layer of plastic reduces light intensity. An inflation fan will be needed to blow air into the area between the two layers to reduce moisture buildup and increase the insulation properties of the cover. The outer layer of plastic is 6 mil and the inner layer is typically 4 mil.

Can a high tunnel be mobile?

Yes. One of the primary objectives of a high tunnel is to lengthen the harvest period. Movable high tunnels may be relocated to existing plots of cropland to accelerate early growth or extend the growing season for that crop. However, they are less airtight than stationary high tunnels. Consult Eliot Coleman's *Winter Harvest Manual* for additional information on design of movable high tunnels.

What type of plastic is used to cover a high tunnel?

Six-mil, four-year, greenhouse-grade polyethylene is a suitable material for covering a high tunnel.

How high should the sidewalls be for a high tunnel?

A sidewall 5 feet high is superior to a 3-foot sidewall with respect to air circulation. For tomatoes, a sidewall at least 5 feet high will permit air to move above the crop canopy.

What warm-season vegetables can be produced in a high tunnel?

Warm-season vegetables are sensitive to frost. Many types of vegetables can be grown successfully in a high tunnel. Many growers have used high tunnels for early tomatoes. Other choices include peppers, summer squash, cucumbers, melons, herbs, eggplant, and snap or pole beans.

What are some examples of cropping patterns for a high tunnel?

At least two crops per year can be produced using a high tunnel. In central Missouri, for example, tomatoes can be planted as early as March within a high tunnel, and harvest can begin in mid-June. Depending on the variety and type of tomato chosen, harvest can continue through July. At this point, the tomatoes can be removed, the soil fertilized and tilled, and a second crop of peppers, cucumbers or beans can be established for fall harvest. If you wish to keep tomatoes in the high tunnel, spring-planted tomatoes will bear fruit through October in Missouri. A cool-season vegetable can be planted in late November and then be either harvested or overwintered in the high tunnel.

How are tomatoes grown within a high tunnel?

Tomatoes are grown on raised beds with organic or plastic mulch. The raised bed (at least 6 inches high) will facilitate drainage and keep the root system warmer. Plastic mulch (black, clear, or infrared-transmitting) will also increase soil temperatures. Drip irrigation is used to water and fertilize the tomatoes through the growing season. Row covers, a lightweight fabric, must be used to provide early frost protection. The tomatoes can be either staked or caged.

How many tomatoes can I plant in a 20' x 96' high tunnel?

The optimal spacing for tomatoes in a high tunnel is 6 square feet per plant. Therefore, approximately 300 plants can be planted per house.

Is pollination of tomatoes adversely affected by the high tunnel?

No. Tomatoes are self-pollinated. Research at the University of Missouri has shown no pollination problems with tomatoes in a high tunnel. Air movement, which reduces humidity and vibrates the flower, is important for good pollination. If you have to keep the vents closed for an extended period, you may want to shake the cages or stakes to facilitate pollination. If you are using row covers, they should be removed when the plants are flowering and the sidewalls are rolled up. If temperatures are projected to fall to 55 degrees F or less, the row covers should remain on the plants. High sidewalls improve cross-ventilation within the high tunnel.

What is an average yield for high tunnel tomatoes?

High tunnel tomatoes average about 10–12 pounds of tomatoes per plant over a four-week harvest period (mid-June to mid-July). The percentage of unmarketable fruit is much lower for high tunnel tomatoes than for field tomatoes.

Do I need to spray tomatoes in a high tunnel for disease and insect control?

High tunnels provide a protected environment for crop growth. However, this does not mean that you will not have any harmful diseases or insects. Protecting the crop from rain will significantly reduce disease problems. However, you should scout your crop for any sign of disease. Pay close attention to the rows nearest the baseboards or doors. Insects encountered on tomatoes in the Universitiy of Missouri high tunnel trials include aphids *(Myzus persicae)*, hornworms *(Protoparce quinquemaculata)* and fruitworms *(Helicoverpa zea)*. Many of these insects can be controlled by biological methods (beneficial insects) or using biological insecticides (Bt insecticides) or by exclusion (closing vents at night).

Can I use pesticides within a high tunnel?

Some pesticides can be used within a high tunnel, but growers must read the label specifically for each crop. Current regulations maintain that when high tunnel sidewall vents are rolled up, the high tunnel may be treated as a field crop. Opening just the end walls is not sufficient for applying pesticides within a high tunnel. When the sides are down, the high tunnel should be treated as a greenhouse. Keep the sidewall vents open for the length of the reentry interval (REI).

Are certain tomato cultivars best suited for high tunnel production?

Any field or garden tomato will perform well in a high tunnel. If the objective is to produce early tomatoes, the best choice would be a hybrid, determinate cultivar that concentrates its fruit-set within a narrow window (4–6 weeks). Indeterminate types will perform well in a high tunnel. However, these types of tomatoes continue to set fruit through the summer and fall and will not yield a large quantity of fruit per harvest. Indeterminate tomatoes are well suited for late summer and fall tomatoes.

Can high-bicarbonate irrigation water be a problem for high tunnel tomatoes?

Using irrigation water that is high in calcium and magnesium can increase the pH of the soil over time and cause nutrient imbalances. Test the water for pH and bicarbonate levels. Using sulfur fertilizers or injecting acids into irrigation water can neutralize the bicarbonates.

For more information about high tunnels

Coleman, Eliot. 1998. ***The Winter Harvest Manual.*** (Four Season Farm, 609 Weir Cove Road, Harborside, ME 04642)

www.hightunnels.org
Web site for the Central Great Plains High Tunnel Collaborative Project

http://plasticulture.cas.psu.edu
Pennsylvania State University Web site for high tunnel horticulture research

http://www.noble.org
Noble Foundation high tunnel research projects

Constructing a High Tunnel

High tunnels are solar-heated, plastic-covered structures that provide a protected environment for high-value crops. These protective structures consist of a series of evenly spaced bows that provide structural support for the polyethylene covering. Most commercial units are available in widths ranging from 14 to 30 feet, and may vary from 48 to 96 feet long. At the University of Missouri, a “Polar” high tunnel kit was purchased from Stuppy Greenhouse Manufacturing, Inc. (Kansas City, Mo.). The dimensions of this structure are 20 feet wide by 12 feet high with bows spaced four feet apart and 5-foot high sidewalls (Figure 1). This structure can be up to 100 feet long.

Selecting the site

The first step in constructing a high tunnel is site selection. The site should be relatively level to reduce the cost of grading. If possible, select a site that has deep, well-drained loam or sandy loam soil. Deep soil facilitates the formation of raised beds; tomatoes have a large root volume requiring deep, well-drained soils. Do not place the high tunnel in a frost pocket where either air or water drainage is a problem. Make site adjustments to allow for surface water runoff. Drainage pipe can be buried around the perimeter of each high tunnel to prevent water from seeping into the structure. Select a parcel of land that is larger than what is immediately needed to allow for expansion if necessary. Additional areas may also be needed to accommodate service or storage buildings. Care should be taken to avoid locations where trees or buildings may cast shadows on the solar-heated structures.

High tunnels should be oriented to facilitate good air movement across the structure. For maximum light interception, high tunnels above 40 degrees north latitude (northern Missouri) should be oriented east–west. For locations below that line, north–south is the optimum orientation. The deciding factor should be prevailing wind direction on your farm. The long axis of the high tunnel should be perpendicular to prevailing winds during spring and summer. Cold, winter winds from the northwest should contact the end wall. Windbreaks on the north sides of high tunnels may be applicable in some areas.

Access to the high tunnel is also important when considering location. Because high tunnels require manual labor to vent, the structures should be in a convenient location to minimize labor cost.

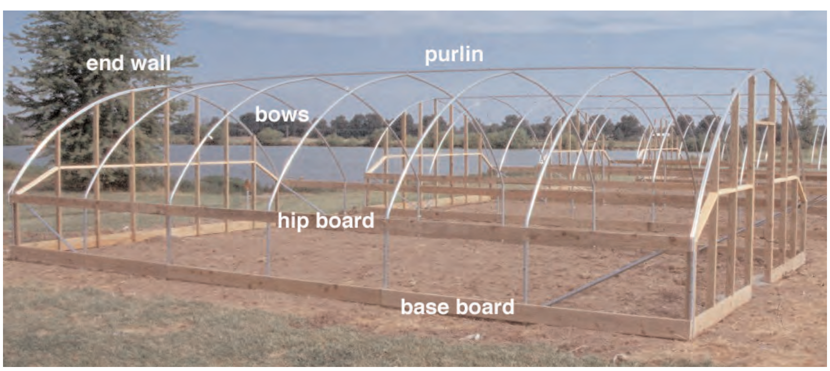


Figure 1. High tunnel components include sidewall, end wall, bows and purlin.

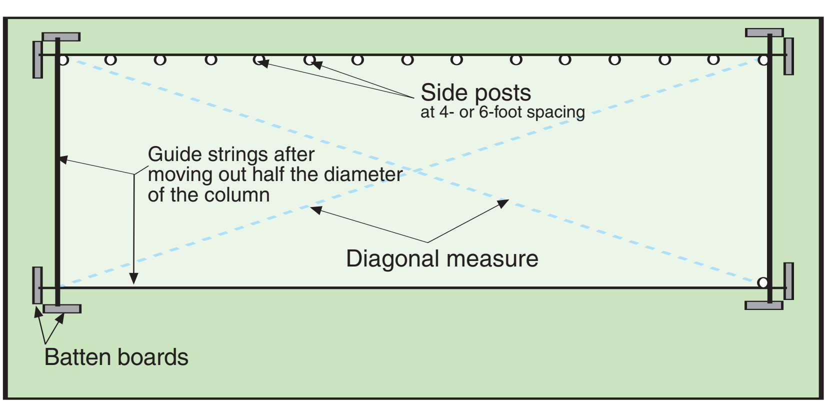


Figure 2. Design layout for high tunnel. (Source: Nagengast, 2003).

Construction

Begin constructing your high tunnel by positioning and squaring the four corner posts. Use a hand-held level to make sure the posts are set vertically in the ground. To check for a square layout of the corner posts, measure each diagonal. The lengths of the two diagonals should be within half an inch of each other.

Use the Pythagorean theorem to set the high tunnel square: the square of the diagonal should equal to the sum of the squares of the two sides of the high tunnel. The diagonal of a 20' x 96' high tunnel is 98.06 feet. Measuring this distance for both diagonals will ensure that your corner posts are set 90 degrees to each other. You may wish to cement the corner posts to add structural integrity to the high tunnel. Set all posts to a depth of 24 inches. Metal posts can be driven into the ground by using a metal fence post driver or by placing a trailer hitch ball on top of the post to protect the post ends and striking the ball with a heavy hammer.

Run a string line from one corner post down the long axis of the tunnel to the corner post on the other end, drive the remaining side posts in the ground to the proper depth (Figure 2). The top of each post should be the same distance from the string line to ensure the proper depth and to keep the bows level.

Installing the bows

Most manufactured high tunnel bows are delivered in two or three pieces. Stuppy's "Polar" unit is delivered in three sections. Assemble a bow by joining two bow sections with a ridge connecter to form an arch. Attach the complete bows to the side posts. At least two people are needed to insert the bows into the side posts. After the bows are in place, the center purlin can be attached to each bow with a purlin bracket (Figure 3). The center purlin sits on top of the bows in the Stuppy "Polar" design, but some manufacturers' purlins will be attached under the high tunnel bows. Additional purlins may be added to give extra stability to the high tunnel. Depending on the width of the structure, there may be one to four purlins per tunnel (Figure 4).

Figure 3. A purlin bracket (left) is used to connect the two bow sections. The center purlin of the Stuppy "Polar Cub" design (right) sits on top of the bows .

Figure 4. Purlins can number from one to four on a high tunnel.

Baseboard and hip board installation

Figure 5. Baseboard and hip board attached to side posts.

Baseboards fastened to the support posts strengthen the foundation of the high tunnel. A 2" x 6" pressure-treated board makes a good baseboard for most applications. Use post or conduit clamps to attach the baseboard to the side posts (Figure 5).

Figure 6. Plastic attached to hip board.

Hip boards add strength to the tunnel and serve as a top point for rolling up the sidewalls. Hip boards should be located 5 feet above the baseboards for maximum ventilation. Attach the hip board in the same manner as the baseboard. Then attach a 1" x 3" board along the top of the hip board. This will serve as the attachment point for the polyethylene covering. Pull the polyethylene over the 1" x 3" board and then install another 1" x 3" board to sandwich the plastic film between the two boards (Figure 6).

End wall construction

End wall designs are numerous (Figure 7). University of Missouri Research High Tunnels are framed so that end wall panels can be removed. Removable end walls allow larger equipment, such as utility tractors, to be operated inside the tunnel (Figure 8). Four 8' x 8' panels are installed on each tunnel. It is also necessary to construct a storage rack near the tunnel locations to allow for easy storage of the

Figure 7. Various end wall designs used on commercial high tunnels.

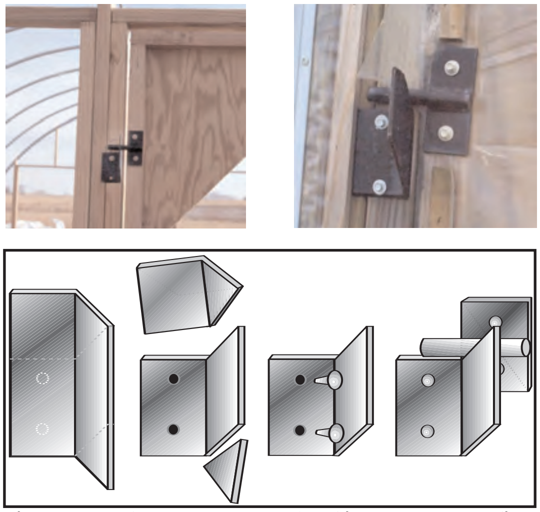


Figure 8. End wall panels are held in place by modified angle-iron brackets.


Figure 9. End wall panels can be removed (left) and stored (right) during the summer.

panels when they are removed for the summer months (Figure 9). Attached to each panel are two handles that make the panels easier to lift. Each panel is held in place by four modified angle-iron gate latches (Figure 8).

The edge of the angle iron attached to the end wall framing was ground down to make the panels easier to remove.

Covering the high tunnel

Plastic films for covering high tunnels should be 6-mil greenhouse-grade plastic with UV light resistance. Greenhouse-grade polyethylene films usually carry a manufacturer's guaranteed life span of three or four years under normal conditions.

Covering the high tunnel should be attempted only when there is little or no wind. Before covering the high tunnel, rough edges on the structure should be taped or smoothed to prevent tearing of the plastic film. Unroll the plastic along one side of the structure and unfold it. For a 20-foot-wide high tunnel, you will need a piece of plastic at least 32 feet wide. Try not to let excessive moisture from rainfall or morning dew settle on the film before installation. Tie a rope to one corner of the plastic and at 20-foot intervals down the sidewall edge. With the plastic wrapped around a tennis ball, a rope can be attached to pull it slowly over the frame. The plastic is easier to handle and pull over the bows when it is dry. Once the film is pulled over the structure, make sure it is square by checking to see that all creases run in a straight line. Attach the film to the frame in four or five places to secure it temporarily while it is being permanently attached. Attach the plastic to the 2" x 6" hip board with the 1" x 3" boards. The cover should come over the top of the upper 1" x 3" board and under the other board as previously described. Keep the plastic tight as you secure the covering.


Figure 10. Wiggle (zigzag) wire is used to secure the plastic to the frame.

During end wall construction, attach aluminum channel lock on top of the two end wall bows. This channel allows the plastic covering to be attached to the bows by using a 13-gauge, high tensile wire called wiggle wire, which locks the polyethylene in place (Figure 10).

Attach the sidewall plastic to a ¾"-diameter PVC pipe to allow the sidewalls to be rolled up (Figure 11). Attach the sidewall plastic to the roll-up pipe with a second PVC pipe that has been ripped in half and screwed to the roll-up pipe.

Handles for the roll-up sidewalls

Figure 11 shows the roll-up sidewall handle design. The PVC pipe handle is easily moved to roll the sidewalls up and down or lock the sidewalls in place. Always roll up the sidewalls in a direction that prevents water from accumulating in the roll.


Figure 11. A ¾-inch PVC t-handle (left) rolls the sidewall vents up (open) or down (closed).

For further information

Nagengast, D. 2003. Siting and building the hoophouse. In: *The Hoophouse Handbook* (L. Byczynski ed.) Fairplain Publications, Lawrence, Kan.

Producing Tomatoes in a High Tunnel

Many vegetable crops can be successfully grown in a high tunnel. Tomatoes are particularly well adapted to production within a high tunnel because tomatoes can be trained to grow vertically by trellising or staking. Early-season tomatoes also reward growers with premium prices because of the difficulty of consistently harvesting field tomatoes before July in the central Great Plains.

Production inputs

A permanent high tunnel should be placed on fertile, unshaded, well-drained soils with a pH in the range of 6.0–7.0. Because high tunnels are manually vented, they should be placed in an accessible location. The soil should be tilled to a depth of 6–8 inches, and nutrients should be applied based on a recent soil test. Tomatoes should be established on a raised bed.

Raised beds will significantly enhance tomato rooting by increasing soil warming, drainage and volume. Tomatoes are a relatively deep-rooted vegetable. An ideal raised bed is about 8–10 inches high and 30–36 inches wide at the top. Typically, a 20' x 96' high tunnel will accommodate five rows of tomatoes. Raised beds can be made with power tillers or compact bed shapers attached to small tractors. After the raised beds are formed, fertilizer, drip tape and plastic mulch can be applied (Figure 12).

Mulch

For early tomato production, black, clear or IRT (infrared transmitting) mulch can be applied to increase soil temperatures and to reduce weed emergence and soil evaporation. For maximum effectiveness, black plastic mulch should be in good contact with the surface of the bed for effective transfer of heat. Embossed plastic mulch will fit tightly over the bed. Clear plastic will increase soil temperatures significantly more than black plastic, but weeds will emerge under the clear film (Table 1). White plastic (white on black or white) will significantly lower soil temperatures and can be used for high tunnel tomato production in late summer or fall.

Organic mulches such as straw, hay or compost can be used for high tunnel tomatoes.

Table 1. Plastic mulch effects on soil temperature.

Mulch type	Soil temperature increase (+) or decrease (–) (F)
Black	+5
Clear	+8–14
Infrared transmitting (IRT)	+5–10
White	-2

Note: Soil temperature at the 2-inch depth.

Source: Penn State University Center for Plasticulture and University of Missouri.

Organic mulches create a favorable environment for many beneficial insects while increasing organic matter. However, some organic mulches (straw or hay) can significantly lower soil temperature and thus would not be effective for warming the soil in the spring. Compost (being dark colored) can increase soil temperatures, but not as effectively as black plastic mulch. Organic mulches can be applied when soil temperatures have increased.

Figure 12. Raised bed with black plastic mulch (1-mil, embossed). Drip tape is placed under the plastic mulch.

Irrigation

Because the high tunnel excludes natural rainfall, irrigation must be provided. Drip irrigation for tomatoes significantly improves marketable yield and overall quality. A uniform application of water reduces fruit cracking and other physiological problems such as blossom end rot. The drip tape (a ¾-inch small, collapsible tube) should be buried slightly below the soil surface 2–3 inches to the side of the plant with the drippers on the top. Eight- or 10-mil tape is acceptable with drippers spaced 4–12 inches apart. A drip system operates at 8–15 psi pressure. (See the Appendix for a list of regional drip irrigation suppliers).

Tomatoes use a large volume of water, especially during fruit sizing. The fruit is about 95 percent water. From fruit set to harvest, 1.5-3 quarts of water per plant may be needed each day.

Soil moisture can be monitored with a tensiometer, a device that measures soil moisture tension in centibars (cb). The drier the soil, the higher the centibar reading from the tensiometer. Place the tensiometer in the center of each raised bed. When 50 percent of the available soil water is depleted, irrigation should occur (see Table 2).

Table 2. Using a tensiometer to monitor soil moisture and irrigate tomatoes.

Soil texture	Soil tension (cb)	Soil moisture status
Sand, loamy sand	5–10	Soil at field capacity. Irrigation is not required.
Sandy loam, loam, silt loam	8	
Clay loam, clay	20–40	
Sand, loamy sand	20–40	Irrigate tomatoes (50% of soil water is depleted). Provide approximately 2 quarts per plant.
Sandy loam, loam, silt loam	40–60	
Clay loam, clay	50–100	

An additional advantage of drip irrigation in a high tunnel is the ability to inject water-soluble nutrients through the drip line as the plant needs them. Generally, large quantities of phosphorus and potassium should not be applied through the drip system. Rather, based on a recent soil test, all the needed phosphorus and most of the potassium can be applied at planting or between cropping cycles within a high tunnel. Additional potassium can be applied during harvest. About 40–50 percent of the total nitrogen requirements for tomatoes can be applied before planting, and the balance can be applied through the drip system over the course of the growing season. Nitrogen requirements for tomatoes depend on the soil quality (i.e., organic matter) and previous cropping history. Generally, for each 1 percent organic matter content of your soil, you can assume that there are 20 pounds of residual nitrogen per acre. Therefore, if you have organic matter levels greater than 3 percent, no *preplant* nitrogen is necessary. However, if your soil organic matter is less than 3 percent, and you have not been supplementing the soil with organic residues, you should apply the equivalent of 1.4 pounds of *actual* nitrogen per 1,000 square feet (equivalent to 60 pounds per acre) at or before transplanting (Table 3). Additional nitrogen can be applied by the drip system at a weekly rate of 8–10 pounds per acre starting two weeks after transplanting. For example, assume a 20' x 96' (1,920 ft^2) high tunnel has five rows of tomatoes spaced 18" x 48". The total plant population in the high tunnel is 320 plants. Providing 8–10 pounds of nitrogen per acre is equivalent to applying 19–24 ounces of calcium nitrate (15.5N-0-0-19Ca) per 1,000 square feet (Table 4). A 20' x 90' high tunnel containing 320 plants require 36–46 ounces of calcium nitrate per week.

Table 3. Nitrogen rates for several granular commercial fertilizer analyses (preplant).

N required (lb per acre)	N per 1,000 ft^2 (oz)	10-10-10 (oz/1,000 ft^2)	13-13-13 (oz/1,000 ft^2)	20-20-20 (oz/1,000 ft^2)
50	18	184	141	92
60	22	220	170	110
75	28	275	212	138
100	37	367	283	184
125	46	459	353	230

Table 4. Amount of several water-soluble fertilizers required to supply nitrogen (fertigation).

N required (lb/acre)	N/1,000 ft^2 (oz)	15.5-0-0† (oz/1,000 ft^2)	34-0-0‡ (oz/1,000 ft^2)	20-20-20 (oz/1,000 ft^2)
2	1	5	2	4
4	1	10	4	7
6	2	14	7	11
8	3	19	9	15
10	4	24	11	19

Notes: †Calcium nitrate ‡Ammonium nitrate

Taking tissue samples periodically through the growing season may be useful. Randomly select 10–12 plants per house. Break the fifth or sixth limb from the top of the plant and place the entire limb in a brown paper bag. Preferably dry the sample before sending to a diagnostic lab for analysis.

Row covers

Row covers are an important component of successful high tunnel tomato production. Row covers are lightweight, spun-bonded polypropylene blankets that are supported loosely over the crop row or canopy. In the field, a light to medium-weight (0.5–0.9 oz/yd^2) row cover will increase air temperature around the crop by 2–6 degrees F, while protecting the crop from adverse weather and insect injury. Using row covers in a high tunnel can significantly increase the average daily temperature. For early tomato production, row covers can be two to three times *more* effective in a tunnel than they are in the field. A medium-weight (single or double layer) row cover should be placed over the plants after transplanting in March. Do not keep row covers on the tomatoes too long. During flowering, you will need to remove the covers to ensure adequate pollination. If temperatures become cold during flowering, the row covers can be reapplied.

In contrast to field conditions, wind currents do not remove trapped thermal energy under the row cover within a high tunnel, and the row cover acts as an insulating layer over the plant. Another option is the use of plastic low tunnels that act as mini-greenhouses (18-24" high) with a single or double layer of plastic (1-mil). Low tunnels can significantly increase air temperatures but must be vented to prevent excessively high temperatures.

Row covers can be kept on the plants from the time of transplanting (mid to late March) until the appearance of the first flower cluster. At this point, they can be removed and kept in reserve in the event of freezing temperatures. If the sidewall vents are rolled up (i.e., ambient temperatures are warmer than 60 degrees) the row covers can be removed at any time. Row covers should be kept on tomato plants if the night temperatures fall below 50 degrees.

Tomato plant characteristics

The tomato is a warm-season vegetable crop that is sensitive to frost and will be killed by freezing temperatures. Tomato plants have either a determinate or an indeterminate growth habit. Determinate tomato vines produce side shoots that terminate in a flower cluster, and the plant reaches a height of 3–4 feet. Therefore, yield is concentrated over a 4- to 6-week period. Indeterminate tomato plants continue to produce additional vines and flower clusters throughout the growing season and may reach 5–7 feet in height.

Tomato plants do not need a specific day length to flower. The flowers are self-pollinated, but physical vibration of the flower by shaking the plant, wind movement, or insect pollination will promote pollination. The optimum temperatures for pollination are 68–75 degrees F at night and 60–90 degrees during the day. At prolonged temperatures below 55 degrees or above 90 degrees, flowers can drop from the plant. High humidity (higher than 80%) can also adversely affect pollination, producing cat-faced (misshapen) fruit. The period between flowering and harvest is about 45 days for most tomato cultivars.

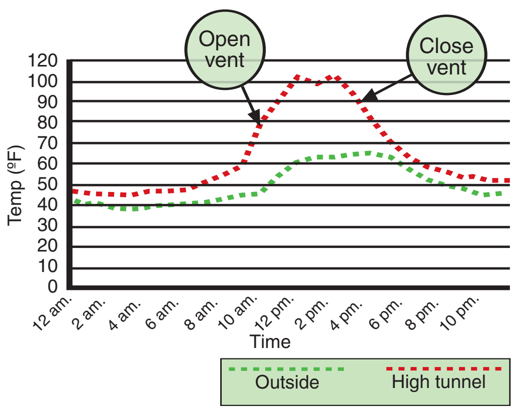


Figure 13. Daily temperature fluctuations in an unvented (single plastic layer) high tunnel, Columbia, Mo. (3/27/02).

Because temperature and humidity affect tomato pollination, yield and fruit quality, the high tunnel environment should be monitored carefully. In early spring, the period of venting is usually between 10 a.m. and 4 p.m. If left unvented, a high tunnel can reach extremely high temperatures (Figure 13). A 60-degree day can produce 100-degree temperatures within the high tunnel. The amount of venting required depends on prevailing winds and sunlight intensity. The goal should be to keep daytime temperatures between 75 and 85 degrees and relative humidity below 80 percent. If there is a forecast of frost, close the vents in midafternoon and place row covers on the plants.

High tunnel tomato culture

Producing transplants

In a high tunnel, tomatoes are usually established by transplants. The critical first step in transplant production is to purchase quality seed of a cultivar that possesses characteristics you prefer. One ounce of tomato seed contains 6,000–12,000 seeds. (See the Appendix for a list of tomato seed suppliers.) The optimum germination temperature for tomato seed is 75 degrees F, and the optimum temperature range for growth of the transplant is 60–70 degrees. Seeds should be sown in a germination flat or 50- to 72-cell tray 5-7 weeks before you anticipate transplanting. Container size is important for early tomato production. Research has revealed that the container for a tomato seedling should be *at least* 2.25 inches in diameter. For example, if the seed is sown in a 72-cell tray, the seedlings can be replanted in a 606 Compack (2.25" x 2" cell) flat beginning at the two-true-leaf stage. Low light or excessive watering, nitrogen or temperature will cause excessive "leggy" growth. Transplants should be fertilized with 100–200 ppm of nitrogen per watering. For example, approximately 1 pound of 20-20-20 can be dissolved in 100 gallons of water for a fertilizer source. A good tomato transplant should be stocky. Tomato transplants can be

Note:
1 oz/gallon = 75 ppm

To determine the parts per million (ppm) of a specific fertilizer nutrient, multiply the percentage of the nutrient by 75. The product will be ppm of the nutrient per ounce of the fertilizer dissolved in 100 gallons of water.

For example, if you wish to prepare a 200 ppm nitrogen solution of 20-20-20,

0.20(75) = 15. Thus, in 1 ounce of 20-20-20 (dissolved in 100 gallons of water), there are 15 ppm of nitrogen. To make a 200 ppm solution, (200 ppm ÷ 15 ppm/oz) 13.3 ounces of 20-20-20 will be needed.

conditioned or "hardened off" before transplanting. Hardening of tomato plants enables the plants to survive the shock of transplanting within the high tunnel in early spring. Plants that are not properly hardened will be slow to start growth after transplanting. Hardening of tomato transplants can be accomplished by taking plants from the greenhouse about 10 days before transplanting and exposing them to outside temperatures (no cooler than 55 degrees) and wind for a few hours each day.

Transplanting

Tomato plants can be transplanted when soil temperatures reach 60 degrees F at a depth of 2 inches. A starter solution of fertilizer (e.g., 9-45-15) should be used to promote root development. Three pounds of the dry material is mixed per 50 gallons of water and one-half pint is applied to each plant. For early tomato production, row covers, raised beds, drip irrigation and plastic mulch are essential. You may wish to invest in portable backup heaters if you feel the risk of a freeze is great.

A tomato plant in a high tunnel should occupy 4–6 square feet of land. Early-yielding

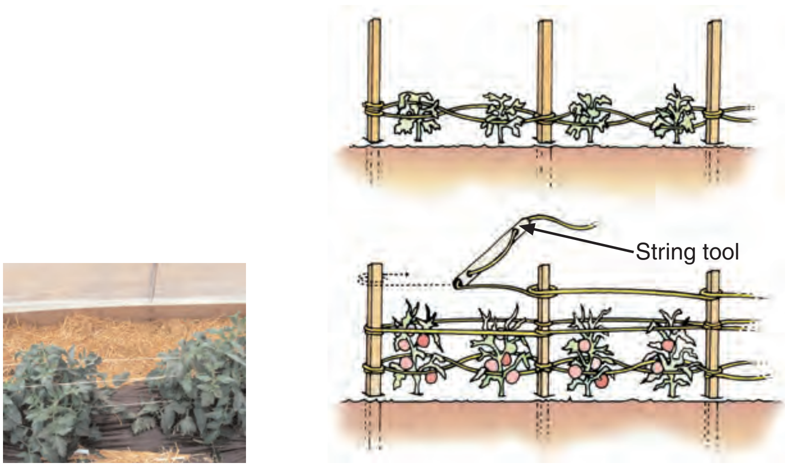


Figure 14. Staking and stringing of tomato plants will improve fruit quality and early marketable yield.

cultivars that do not produce a large vine can be spaced closer than midseason cultivars or those that tend to have vigorous vines.

Figure 15. Pruning (suckering) tomato plants accelerates early harvest.

Training and pruning

Training tomatoes within a high tunnel is very important. When tomato are staked, light interception and disease tolerance are improved and the plant is more likely to set early fruit, and disease tolerance is improved. For a high

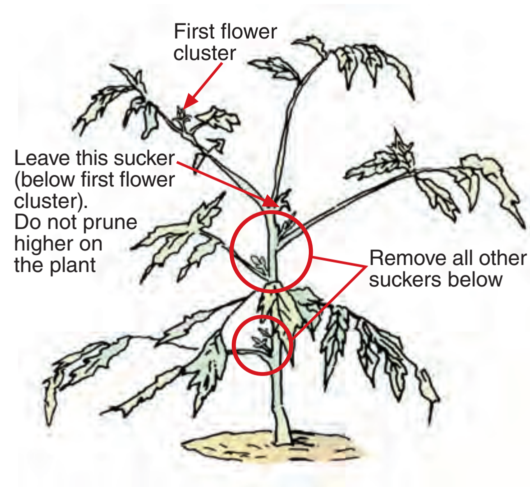


Figure 16. Remove all but one sucker below the first flower cluster to achieve balance between vine and fruit growth.

tunnel, one of the preferred ways to train tomatoes for early harvest is the stake-and-weave system. Drive a 48–52" x 1" square wooden stake (or metal rebar) that is driven between every other tomato plant (Figure 14). When the tomato plants reach a height of 12 inches, the first string can be applied. Nylon plastic twine is the best source of string. Every 6 inches of new growth will require a new string to provide support for the tomato vine and fruit load. Caging tomatoes is another option for training. If you choose to trellis tomatoes from the roof frame, make certain your high tunnel frame can support the crop load. Otherwise, tensile wire supported by metal posts can be used to trellis the vines.

Pruning, the removal of suckers or axillary shoots that grow between the leaf and the main stem, will accelerate early harvest and improve disease tolerance by enhancing air circulation around the plant (Figure 15). While pruning may be too labor intensive for field production, tomatoes in a high tunnel should be pruned if the objective is early harvest. Pruning will not increase total marketable yield. The purpose of pruning is to achieve a balance between vine and fruit growth. Remove all suckers *up to* the one below the first flower cluster, resulting in two stems per plant (Figure 16). Prune when the suckers are less than 4 inches long, and do not prune the plants if they are wet. After pruning, you may wish to apply a labeled fungicide to protect against disease outbreak.

See Table 5 for a guide to troubleshooting problems with tomatoes in high tunnels.

Table 5. Troubleshooting tomato problems in a high tunnel.

Problem	Possible cause	Solution
Flowers falling off plants	Temperatures are either too cool or too warm.	Proper venting for temperature management
	Thrips	See *Midwest Vegetable Production Guide for Commercial Growers*
Flowers fuse together	Too cool.	Proper temperature management
Fruit catfaced or misshapen	Pollination disorder.	Humidity may be too high or temperature too low.
Cupping or rolling of leaves	If the upper leaves experience cupping or rolling, check for aphids. Aphids produce sticky excrement that attracts flies and ants and is colonized by a dark fungus.	Aphids can be controlled by using registered, labeled organic or synthetic pesticides and releasing beneficial insects.
	Some early-season cultivars roll or cup their leaves when they have a heavy fruit load.	Genetics
	Water stress (excess or deficiency)	Irrigation management
Poor fruit set	Temperatures are too high or low, or humidity is excessive.	Temperature management. Do not keep row covers on plants too long.
	Flowers are not being vibrated enough for pollination.	Roll up sidewalls if temperature permits. Shake tomato stakes to promote pollen release. Use bumblebees.
Fruit has gray mold on the stem end	Gray mold *(Botrytis)* fungus	Disease that is promoted by high humidity and cool, cloudy weather. Vent high tunnel properly. Use labeled fungicides, and increase air circulation around the fruit.
Border rows have fruit with holes. Foliage feeding.	Worm feeding	Bt insecticides should be applied every 8–14 days beginning at flowering. If worms are visible, you may wish to use another labeled pesticide.
Stem lesions cause the plant to wilt.	Disease	Have plants diagnosed by your local extension specialist.
Fruit fails to ripen	Temperature	If picking during hot weather, use a shade cloth. Late fall tomatoes may not ripen because of low light and temperatures.
Black spots on bottom of fruit	Blossom end rot	Blossom end rot is caused by a localized deficiency of calcium to the developing fruit. Make sure your soil has medium to high calcium levels; water uniformly; do not overapply NH_4 fertilizers or overprune. Calcium can be applied through the drip system. Do not apply foliar calcium.
Fruit cracking	Irregular watering	Mulch and water uniformly.

Table 6. Some tomato varieties for high tunnel production.

Variety	Days to harvest	Disease resistance	Comments
Determinate			
BHN 543	72	F_{12} V_1	Midseason early; Excellent size, shape and quality.
Carolina Gold	75	F_{12} V_1 GW	Yellow (tangerine) colored fruit; Vigorous vine. Excellent quality.
Florida 47	75	F_{12} V_1	Large, smooth, crack-resistant fruit; Good quality; Vine slightly less vigorous than Fl 91.
Florida 91	72	F_{12} V_1	Large, smooth, crack-resistant fruit. Heat-set variety with good disease tolerance.
Floralina	72	F_{123} V_1	Large, smooth, crack-resistant fruit. Very good taste.
Merced	69	F_{12} V_1	Early; Good quality. Has a tendency to crack in the field but not the high tunnel.
Mountain Fresh	78	F_{12} V_1	Excellent midseason variety; Very good quality. Vigorous vine. Good disease tolerance.
Mountain Spring	70	F_{12} V_1	Early; Excellent fruit size.
Sunleaper	70	F_{12} V_1	Heat-set variety good for summer and fall production.
Indeterminate			
Trust		F_{12} V_1	Excellent quality and yield
Big Beef	73	F_{12} V_1	Excellent yield

[1]This list is not intended to include every variety that may perform well in a high tunnel.
F = *Fusarium* wilt race 1, 2, 3 V = *Verticillium* wilt GW = Gray wall

Figure 17. Tomatoes can be packed in single- (15 lb) or multiple-layer (20–25 lb) boxes for market.

Variety selection

The essential first step in successful high-tunnel tomato production is selection of a suitable variety. Table 6 lists several varieties that have performed well in high tunnel trials at the University of Missouri.

Harvest and postharvest handling

Tomatoes can be harvested for vine-ripe fruit about 45 days after flowering. However, tomatoes continue to ripen when picked at any stage from mature green onward. If high tunnel tomato production is extended into late fall, mature green fruit can be harvested before a hard freeze and allowed to ripen at room temperature. Mature green fruit can also be harvested and allowed to ripen at room temperature. Mature green fruit exhibits a color break in the shape of a star at the blossom end. Another way to gauge maturity is to cut the fruit, and if the seeds are cut, the tomato is not ready to harvest.

Tomatoes are graded as USDA No. 1, No. 2, and No. 3. Within each grade class, tomatoes can be sized as jumbo (more than 3.5" diameter); extra large (2.75" to 3.5"); large (2.5" to 2.75") and medium/small (less than 2.5"). Boxes or shipping containers for tomatoes vary. Typically tomatoes are packed in 20- to 25-pound boxes or single layer, 15-pound boxes (Figure 17).

Do not refrigerate vine-ripe tomatoes or allow the fruit to be exposed to temperatures higher than 85 degrees. If tomatoes are held in storage, the temperatukre should be 50–75 degrees F with 85–90 percent relative humidity. On hot days, pulp temperature of tomatoes can be 20 degrees warmer than air temperatures. Picking fruit early in the morning or in the evening reduces field heat. Shade cloth can significantly lower temperatures in the high tunnel during harvest in late June and July. Tomatoes can be packed immediately after harvest without washing, or growers can clean the fruit with chlorinated water. If the fruit is washed, do not use ice or cold water, and the water should be properly chlorinated for sanitation (125 ppm). The pH of the wash water should be 6.5–7.0. A washing and sizing unit can be used to clean and size harvested fruit. Avoid storing vine-ripe tomatoes with fruits such as apples or cantaloupes. These fruits emit ethylene, a gas hormone that accelerates ripening of tomatoes and can reduce their shelf life.

High Tunnel Temperature Management

Temperature management is one of the most critical components of successful high tunnel tomato production. Early-season tomatoes can be successfully grown in the central Midwest without supplemental heat. Using raised beds, plastic mulch and row covers in the high tunnel will significantly increase average daily temperatures. Adding a second layer of polyethylene covering will reduce heat loss and the formation of condensate on the inside surface of the cover. Growers who wish to use heaters may find them useful in protecting the crop during a hard freeze and in accelerating growth of the tomatoes.

The optimum temperature for growth of the tomato plant is 70–75 degrees F. Average daily temperatures should not be lower than 65 degrees. Temperatures below 55 degrees during flowering can reduce fruit set and produce misshapen fruit. Growers must monitor temperatures carefully by placing a minimum/maximum thermometer in the center of each high tunnel at the height of the tomato canopy. Shade the thermometer to avoid false high readings due to direct exposure to sunlight.

For early-tomato production, April is the most variable month for temperature within the high tunnel. Often, the vents are adjusted three or more times per day to maintain an optimum temperature. Roof vents or vents at the top of the end walls may be useful in preventing excessive heat and humidity buildup within the high tunnel.

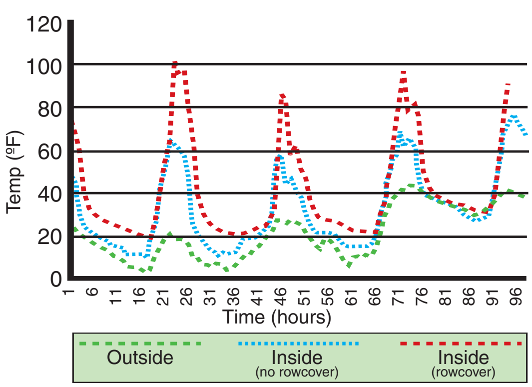


Figure 19. January 16-20, 2003. Row covers (double layer; lightweight) were used to overwinter lettuce with excellent results.

Extremely high temperatures (above 90 degrees) can cause tomato flowers of some cultivars to abscise and will prevent the tomato from developing a uniform red color. High temperatures cause the tomato leaves to turn brown at the margins; the plant looks almost as if it has been in a furnace. Using shade fabric (30–50%) from late June through July harvest will significantly lower temperatures within the high tunnel.

Figure 18. Shade cloth applied over the high tunnel moderates midsummer temperatures.

Shade cloth can be applied externally over the high tunnel in June and removed in early fall (Figure 18). The shade cloth should not cover the sidewall vents. To calculate the width of shade cloth needed, use the following formula for a semicircular (arched) structure:

$$((W/2) \times 3.14) - (H_{sw} \times 2),$$

where W = width of the high tunnel and H_{sw} = height of the sidewalls.

Figures 19–25 show daily temperature cycles throughout the 2003 growing season as recorded in the University of Missouri high tunnel trials.

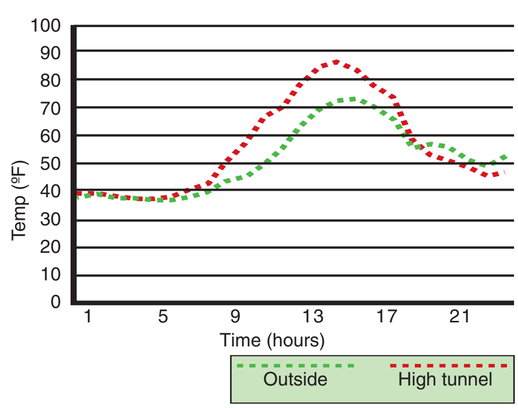


Figure 20. March 15, 2003. Tomatoes were transplanted. Ambient conditions were sunny and warm. All vents were closed. The average 24-hour temperature in the high tunnel was 56 degrees F relative to 51 degrees F ambient temperature. The growing degree day (gdd) base temperature for tomatoes below which growth is negligible is 51 degrees F.

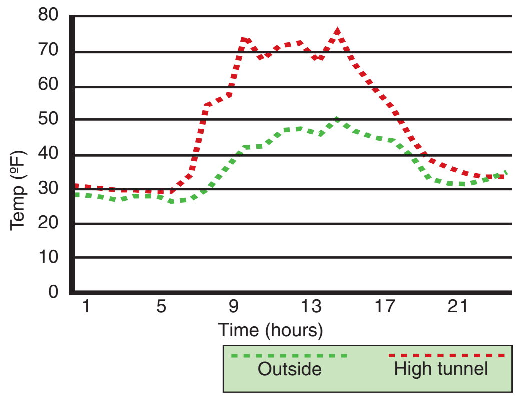


Figure 21. March 30, 2003. Ambient conditions: Cool, sunny with vents closed. Twenty-four hour temperature average within the high tunnel was 48 degrees F compared with 36 degrees F ambient conditions.

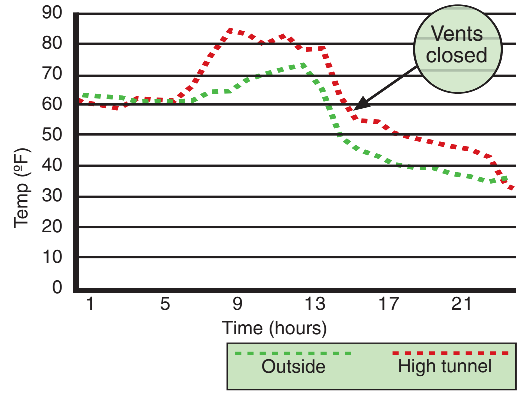


Figure 22. April 4, 2003. Warm morning, then turning colder through the day. Winds WNW; vents opened on east side and closed at 3 p.m.

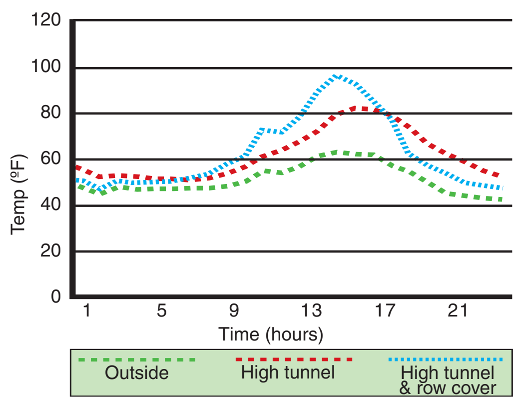


Figure 23. April 21, 2003. Flowering of tomatoes observed. Ambient conditions: Cloudy, cool morning; Sunny afternoon. Vents closed. Single layer of lightweight row cover used.

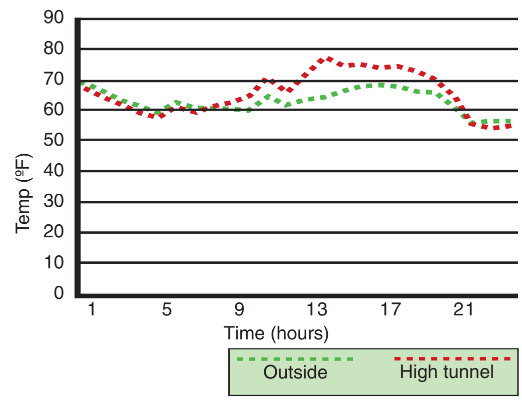


Figure 24. May 31, 2003. Ambient conditions: Cloudy, cool. Vents open until 6 p.m.

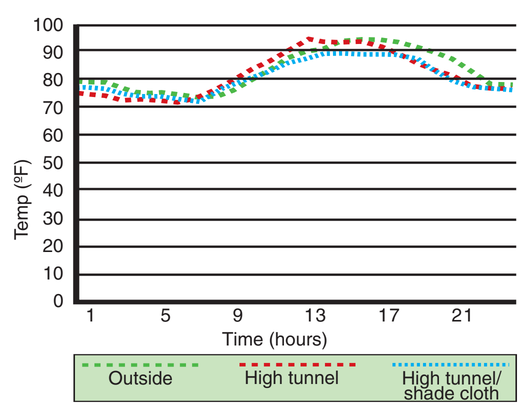


Figure 25. July 4, 2003. Tomato harvest. Shade cloth (47% black) significantly lowered temperatures and improved ripening of high tunnel tomatoes.

Cropping Systems for Tomatoes in High Tunnels

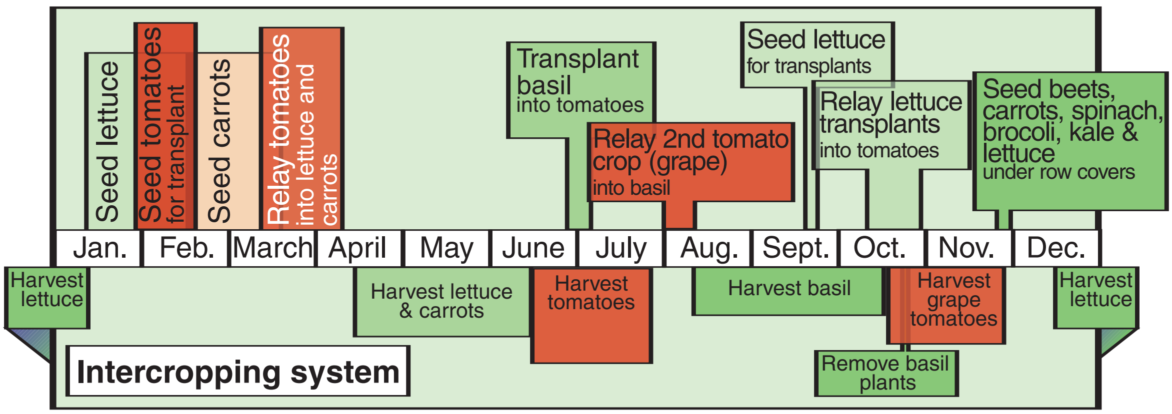


Figure 26. A hypothetical intercropping system for tomatoes in a high tunnel in central Missouri.

Intercropping is the growing of two or more crops within the same production area during part of the life cycle of each crop. Intercropping in a high tunnel allows growers to produce many vegetables within a limited space and thus improve the output of the high tunnel. Interplanting one vegetable with another after the first vegetable has become established is called *relay intercropping* (Figure 26).

Cropping system I
Tomatoes interplanted with lettuce

Starting in January, leaf lettuce can be direct seeded onto preformed raised beds within the high tunnel (Figure 27). Each raised bed is 24–30 inches wide by 6–10 inches high. The lettuce is direct seeded as two or three rows per bed, 6–8 inches apart. In March, tomatoes can be relay planted into the existing lettuce bed (Figure 28). Because the root systems of lettuce and tomatoes do not compete, fertilization practices for the tomato can be used for both crops without diminishing the yield of either. Lettuce harvest begins in April and extends through mid-June. Peak yields of lettuce occur before tomatoes set fruit. Tomato harvest begins in mid-June and extends through July. The lettuce does not accumulate nitrates. Both crops are able to maximize yields without competing with each other.

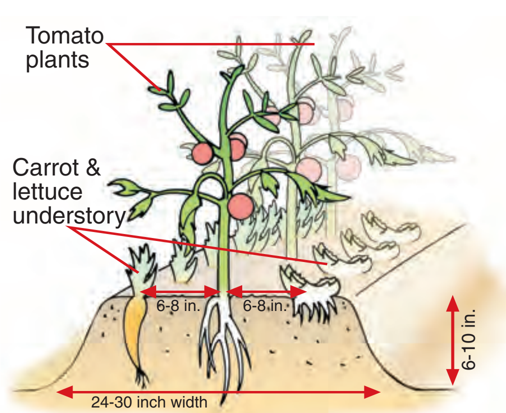


Figure 27. Cool-season crops can be interplanted with tomatoes in preformed raised beds.

Figure 28. Lettuce, carrots and basil are among the crops that can be intercropped successfully with tomatoes in a high tunnel.

Cropping system II
Tomatoes interplanted with carrots

Carrots can be seeded as soon as soil temperatures reach 45 degrees F. For example, carrots can be seeded from February through early April in a high tunnel. Tomatoes can be relay interplanted into the carrot bed with no loss in yield of either crop. The carrots can be harvested one month to one week before harvest of the tomatoes begins.

Cropping system III
Tomatoes interplanted with basil

Basil is often listed as a companion plant that repels tomato hornworm. It can be relay planted (from transplants) into existing tomato beds in early July after the carrot or lettuce harvest has concluded. Basil is a warm-season herb that grows well in hot weather. Harvest of basil will typically run from early August through October. The tomatoes can be left in place or removed after peak harvest in late July. Grape or cherry tomatoes can be planted into the existing beds with basil.

Cropping system IV
Overwintering cool-season vegetables

After final harvest of tomatoes in mid to late November, a 100-day cool-season production window opens in the high tunnel. Hardy vegetables such as broccoli (specialty and heading), kale, spinach, tatsoi, carrots, beets and lettuce can be direct seeded, germinated and overwintered under row covers within the high tunnel (Figure 29). The lettuce, spinach, miscellaneous salad greens and kale can be harvested before mid-March in central Missouri. Other cool-season vegetables may require a longer season.

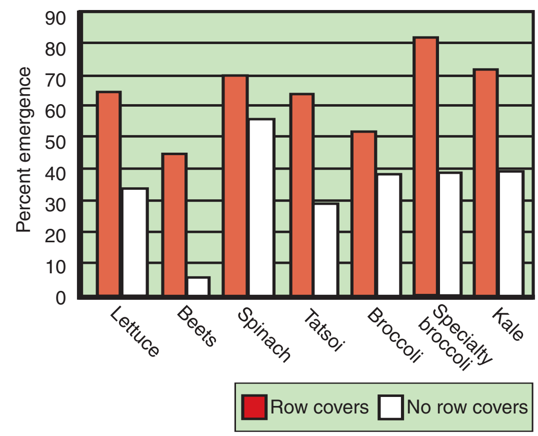


Figure 29. Row covers for winter crops significantly improve germination.
Source: Data from University of Missouri Research High Tunnels, 2003.

High Tunnel Tomato Pest Management

High tunnels provide a protected environment for crop growth and development that restricts many pest outbreaks. However, certain pests can invade high tunnel tomatoes. Scouting rows and individual plants for disease and insect problems is essential. A critical strategy for preventing diseases within a high tunnel is complete removal of tomato residue between crops. Remove vines, fruit and roots from the plant beds.

Tomato diseases

Early blight *(Alternaria solani)*

Symptoms of early blight appear first on the lower leaves of tomato plants. The disease progresses up the plant canopy, eventually infecting the fruit. Leaf lesions of this fungus are rather distinctive with zonal (target board) patterns (Figure 30). Stem lesions can form at the soil line, causing the plant to wilt. As the disease develops, the plant loses its leaves and eventually succumbs to the disease.

Although early blight is more common in field tomatoes, it can appear on high tunnel tomatoes. High humidity promotes early blight infection. Roll up sidewalls to increase ventilation and remove excess humidity. Practice good sanitation by removing infected plants from the high tunnel. Early blight will survive on decayed plant material in the soil. Use labeled fungicides such as chlorothalonil or azoxystrobin. Consult the MU publication MX 384, *Midwest Vegetable Production Guide for Commercial Growers*, for more information on disease management.

Photo credit: T. Baker

Figure 30. Symptoms of early blight include zonal or concentric lesions on the lower leaf canopy. The entire plant eventually becomes infected, resulting in leaf loss and death.

Gray mold *(Botrytis cinerea)*

Gray mold, often called *Botrytis*, is a problem on early-season tomatoes and thrives in a humid, cool high tunnel during overcast days. The disease appears as a gray, fuzzy growth on leaves, flowers and stems of fruit (Figure 31). On fruit, gray mold makes a cloudy spot, or "ghost spot." Improving ventilation within the high tunnels and around the tomato vines (pruning) will help prevent gray mold outbreaks. Close spacing of tomatoes within the row can initiate gray mold infection. Labeled fungicides including *Exotherm Termil* (chlorothalonil) can be used.

Photo credit: R. Snyder

Figure 31. Gray mold infection on leaves and tomato fruit. *Botrytis* spores can germinate on dead flower petals.

Late blight *(Phytophthora infestans)*

Late blight can also be a serious disease of early tomatoes in a high tunnel. Lesions on the stem (Figure 32) cause the plant to wilt and eventually collapse. The plant has a scorched appearance. Infected leaves turn brown rapidly and fall from the plant. Late blight is favored by cool, damp nights and warm days. Follow control measures similar to those for early blight.

Figure 32. Late blight lesions on leaves and stems of high tunnel tomatoes.

Sclerotinia stem rot *(Sclerotinia sclerotiorum)*

Sclerotinia stem rot is a disease favored by cool, moist weather. Infection usually occurs at the time of flowering and lesions are observed in stem joints and at the soil line. Eventually, large sections of the stem become invaded and the stem develops a dry rot. Within the dry, rotted stem are small, black sclerotia that will initiate the disease (Figure 33). The plant exhibits wilting and loss of foliage. Remove infected plants. Avoid using manure as a soil amendment unless it has been properly composted.

Figure 33. Hard, black sclerotia within the tomato stem indicate Sclerotinia stem rot.

Bacterial speck *(Pseudomonas syringae)* & bacterial spot *(Xanthomonas campestris)*

Bacterial speck and spot are two potentially serious diseases of tomatoes. The environment within a high tunnel usually prevents bacterial disease outbreaks, but infection can be introduced from infected transplants or stakes. Bacterial spot occurs as dark angular spots on the leaves with scabs on the fruit (Figure 35). Bacterial speck produces similar leaf lesions but with small, black specks on developing fruit. Bacterial spot is favored by warm, wet weather while bacterial speck occurs most often during cool, wet weather. Use clean seed. Do not use wooden tomato stakes from field plots that have had bacterial spot or speck infection unless the stakes have been sterilized. Consult the *Midwest Vegetable Production Guide for Commercial Growers* for further information on controlling these bacterial diseases.

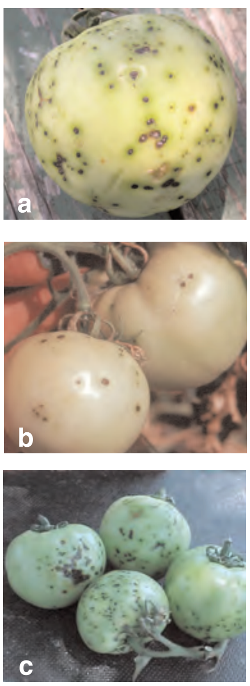


Figure 35. Bacterial speck (a & b) and bacterial spot (c) of tomato fruit.

Septoria leaf spot *(Septoria lycopersici)*

Septoria leaf spot appears on the lower leaves as a circular lesion with a gray center (Figure 34). Fruit infection does not occur. Adequate ventilation is important for control of Septoria leaf spot in the high tunnel. Avoid using stakes from field tomatoes that have been infected.

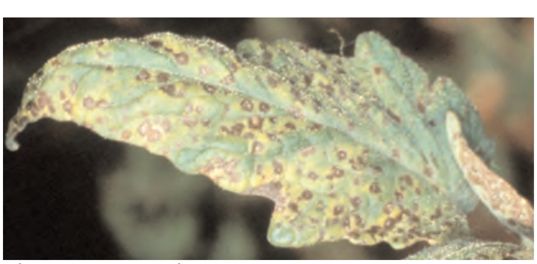


Figure 34. Septoria leaf spot.

Tomato insects

Stink bug *(Euschistus servus)* or *(Acrosternum hilare)*

Stink bugs can be a serious problem to tomatoes within a high tunnel. Damage is caused by adult stink bugs feeding on developing or ripe fruit and creating cloudy spots on the fruit (Figure 36). Scout rows closest to vents or doors for stink bugs. Since stink bugs are attracted to many weeds, maintain a mowed, 100-foot perimeter around the high tunnel.

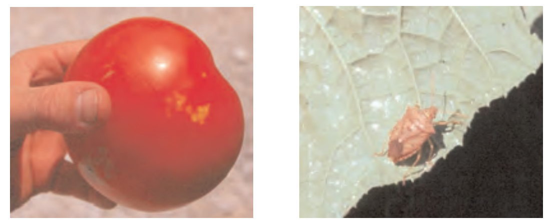


Figure 36. Stink bug feeding injury to tomato fruit is often seen as a cloudy spot.

Fruitworm *(Helicoverpa zea)*

The tomato fruitworm is also known as the corn earworm and cotton bollworm (Figure 37). Nocturnal (night) moths are attracted to tomatoes during flowering. Keeping vents closed during the night may lessen problems with this pest. Use *Bt* insecticides (Dipel) to control worms, including hornworms, cutworms, and armyworms. Note that *Bt* is only effective against young worms. Therefore, scouting and early detection are crucial. Other worm pests include hornworms, cutworms and armyworms.

Figure 37. Tomato fruitworm damage to tomato fruits. Fruitworms usually begin feeding from the calyx (stem) end of the fruit.

Aphids (Aphididae)

Aphids are soft-bodied insects that can thrive on tomato plants in a high tunnel (Figure 38). High humidity and mild weather create a favorable environment for aphid population development. Aphids damage tomato plants by extracting sap from the leaves and stems (usually from the apical growth) and excreting a sugary mixture called honeydew that covers and discolors the fruit and leaves. Aphids typically move from concentrated areas, or "hotspots," in the high tunnel. Early detection and control are critical. Natural enemies of aphids include lady beetles, syrphid flies, braconid wasps and lacewings. However, natural populations may not be present early in the season. Several biological controls are available (see Appendix for a list of suppliers). *Lady beetles* are effective as both larvae and adults and may eat as many as 50-300 aphids per day. Lady beetles are particularly effective if you have a large aphid population in the high tunnel.

Figure 38. Aphids cluster at growing tips and under the leaves, extracting sap and weakening plants. Scout plants regularly.

In addition, use of insect exclusion screens may be appropriate. Additional management options are discussed in the *Midwest Vegetable Production Guide for Commercial Growers*.

Flower thrips *(Frankliniella tritici)*

Thrips are small, slender insects that feed on tomato flowers, leaves and developing fruit (Figure 39). Damage is often observed on the leaves as a silvery tissue caused by the thrips rupturing plant cells. Feeding by thrips on flowers can cause pollination problems and bloom drop. Fruit damage appears as small, yellow flecks on the fruit. Many thrips enter high tunnels on the transplants. Inspect the transplants carefully before planting. Thrips are attracted to terminal growth and flowers of the tomato plant.

Figure 39. Thrips damage to greenhouse cucumber leaf.

Spider mites (Acari: Tetranychidae)

Spider mites become a problem during hot, dry weather. Mites congregate on the lower surface of the leaf, and damage is observed as small, yellowish white spots. Eventually the entire leaf turns brown and falls from the plant, exposing the fruit to sunburn. When populations of mites are high, silk webbing is observed. Inspect tomato plants for mites near doors and vents. Keep broadleaf weeds out of the high tunnel. Many weeds serve as hosts for spider mites, so maintain a mowed area around the high tunnel.

Growers who wish to reduce insecticide applications can employ one or more of the following strategies:

- Use "soft" pesticides that target harmful insects only.
- Scout tomato plants routinely to detect early invasion.
- Treat only "hot spots" in the high tunnel.
- Encourage natural populations of beneficial insects or release beneficial insects in the high tunnel.

Tomato physiological disorders

Blossom end rot

Blossom end rot is a physiological disorder that affects tomatoes, peppers and watermelons. Blossom end rot is a deficiency of calcium in the developing fruit. The blossom end of the tomato fruit develops a dry rot that eventually rots the fruit (Figure 40). The calcium deficiency may be caused by

Photo credit: T. Baker

Figure 40. Blossom end rot of tomato fruit.

low soil calcium (low soil pH), inadequate watering, overpruning, overapplication of ammonium fertilizer, or genetics. The combination of adequate calcium, mulching and even watering prevents blossom end rot. Foliar applications of calcium are relatively ineffective in controlling this disorder.

Yellow shoulder disorder

Yellow shoulder disorder can develop on tomato fruits within the high tunnel. Affected fruit will not develop red color when temperatures exceed 92 degrees. The apical or shoulder of the fruit will develop a yellow color with internal white tissue (Figure 41). The exact cause of yellow shoulder disorder is not known. However, this disorder can be caused by poor fruit shading. Temperatures of fruit exposed directly to the sun can be extremely high, preventing full color development. Proper fertilization, choosing good cultivars and the use of shade cloth can prevent this problem.

Figure 41. Yellow shoulder (above) and internal white tissue (top right) of tomato fruit.

Green shoulder

Figure 42. Green shoulder (with radial cracking) of tomato fruit.

Green shoulder (green back) is a physiological disorder that is observed as a failure of the tomato fruit to ripen toward the stem end (Figure 42). Instead of developing a yellow color (like yellow shoulder disorder), the fruit tissue remains green. Much like yellow shoulder disorder, green shoulder is commonly observed on fruit that has been exposed to high light and temperature. Choose cultivars that have the uniform ripening gene (UG) for even color development.

Shoulder checking

Shoulder checking is usually observed on fall tomatoes in Missouri high tunnels. Typically the fruit shows small, concentric cracks on the stem end (Figure 43). The tomatoes develop a russet appearance. Shoulder checking is triggered by alternating periods of cool, cloudy weather with warm, sunny (dry) weather. Rapid movement of water and photosynthates into the fruit causes the cracking. Water that condenses on the fruit can also cause this problem.

Figure 43. Shoulder checking on 'Carolina Gold' tomato. Small "microcracks" turn dark, making the fruit unmarketable.

Graywall (Blotchy ripening)

Graywall develops on mature green fruit before harvest. When the tomato changes color, gray, discolored areas of the fruit are present (Figure 44). Graywall can be caused by several continuous days of cloudy weather, excessive nitrogen, high soil moisture and possibly low potassium. Some cultivars are resistant to graywall.

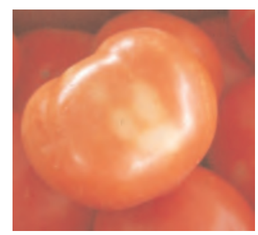


Figure 44. Graywall on tomato fruit.

For further information

Midwest Vegetable Production Guide for Commercial Growers 2004. MU publication MX-384. University of Missouri Extension, University of Missouri-Columbia.

Marketing & Economics of High Tunnel Tomatoes

Market outlets for high tunnel tomatoes include wholesale produce auctions, restaurants, local farmers' markets, direct store delivery, community-supported agriculture (CSA) and on-farm sales. Wholesale produce auctions are becoming increasingly popular in the central Midwest as market options for produce growers. A produce auction is a grower cooperative that provides growers the opportunity to sell locally grown produce directly to consumers or retail stores without using brokers or shippers. Usually organized as a limited liability corporation, grower-members deliver their produce to the auction as lots the same morning as the auction, and the produce is auctioned to buyers. The cooperative deducts a commission (usually 7–10%) that is used to operate the cooperative and pay the salary of the market manager.

Prices at produce auctions are erratic given the direct link between buyers and sellers. Low prices often encourage more buyers for future auctions, resulting in a price upswing. Capital requirements for a produce auction are relatively small because produce is not stored for any length of time. Wholesale tomato prices at produce auctions are generally within the range of \$1.00–1.50/lb from mid-June through early July (Figure 45).

Community-supported agriculture is a community of individuals who pledge support to a farm operation so that the farmland becomes the "community's farm," and the growers and consumers provide mutual support and share the risks and benefits of food production. Members or shareholders of the farm or garden pledge in advance to cover the expected costs of the farm operation and farmer's salary. In return, they receive shares in the farm's harvest throughout the growing season, as well as satisfaction gained from reconnecting to the land. Members also share in the risks of farming, including poor harvest due to unfavorable weather or pests. Some CSA farms may allow members to share in the farm work. High tunnels can be a successful component of community-supported agriculture by allowing farmers to produce more fruits and vegetables in a given season. High tunnels are also suitable for use in organic or natural farming because many crops can be grown with much less pest invasion with high tunnel culture.

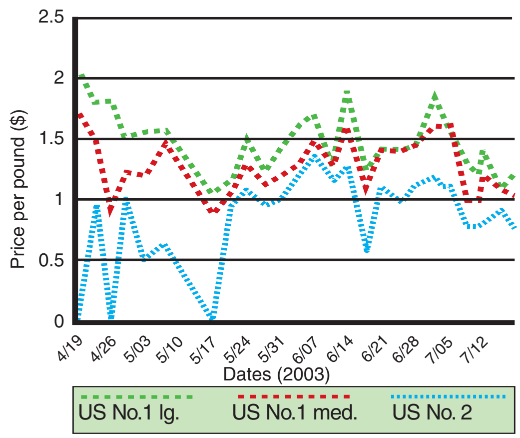


Figure 45. Wholesale tomato prices at auction. Source: Central Missouri Produce Auction, 2002 prices recorded as "0" indicate no U.S. No. 2 tomatoes sold at that auction.

Restaurants also desire to purchase locally grown, out-of-season produce from high tunnels. In a 2002 survey of restaurants in the St. Louis region, 98 percent of surveyed chefs indicated a desire to purchase vine-ripe, locally grown tomatoes (Figure 46). Many chefs expressed an interest in purchasing heirloom tomato varieties. Research has indicated that heirloom tomatoes are easier to produce in a high tunnel than in the open field. Other vegetables such as specialty melons, cucumbers, squash, peppers and cool-season vegetables, including salad crops, are in high demand by many local restaurants. Scheduling production is critical when dealing with a

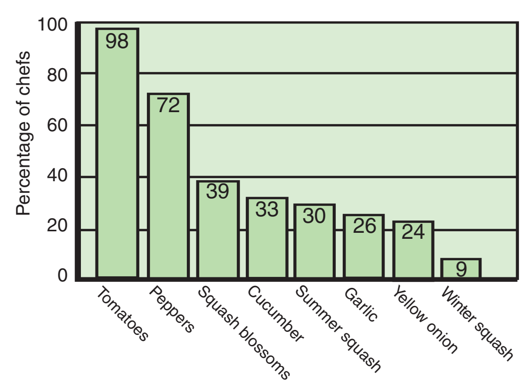


Figure 46. Tomatoes are the most desired warm-season vegetable.
Source: Data from restaurant survey in St. Louis, Mo., 2002.

restaurant. Contact your local restaurants to determine which vegetables are desired through the year.

Direct store delivery is another potential direct marketing option. Independent supermarkets have an interest in purchasing "home grown" tomatoes that can be produced earlier or later in a high tunnel. Supermarkets usually require product liability insurance.

Setting the price for high tunnel tomatoes is critical. Because high tunnels enable early- and late-season production, growers may have more control over price. To determine a fair market price, growers should know their costs of production (Table 7). High tunnel tomato costs of production can be separated into categories:

- **Soil preparation:** Includes soil testing, tilling, fertilizer/compost, raised bed formation, irrigation and mulch application. Growers often fail to include their own labor. However, including this within the budget is critical. The budget in Table 6 assumes an hourly wage rate plus benefits of $10/hour.
- **Seeding or transplanting:** Plant costs are approximately $41 per 1,000 square feet.
- **Production costs:** Includes all inputs necessary to grow high tunnel tomatoes.
- **Harvesting costs:** Labor is the dominant cost associated with harvesting high tunnel tomatoes. Twenty worker-hours per 170 plants (1,000 ft^2) will be required.
- **Postharvest costs:** Growers who wish to separate tomatoes by grade class and rebox fruit will include these costs. Also include labels if appropriate. Box costs are $1/box.
- **Marketing costs:** Include delivery.
- **Total production costs** are $5.49/plant.

Fixed costs are expenses that are incurred regardless of the level of production in the high tunnel (Table 8). Typical fixed costs include the high tunnel, shade cloth, machinery depreciation, etc. Fixed costs are $155/1,000 ft^2.

High tunnel early-season tomatoes yield approximately 8–12 pounds per plant (Table 9). Thus a 2,000-square-foot commercial high tunnel can produce 1,360–4,080 pounds of marketable fruit. To cover production costs, growers must receive more than $.45/lb for a high yield and more than $.68/lb for a low yield.

For more information on tomato pricing

Truck Patch News
P.O. Box 101
Mt. Hope, OH 44660
(Prices from produce auctions)

Growing for Market
P.O. Box 3747
Lawrence, KS 66046
www.growingformarket.com

The Packer (Newspaper)
www.thepacker.com
(wholesale prices)

USDA Agricultural Marketing Service
www.ams.usda.gov/marketnews.htm

Table 7. High tunnel tomato budget (per 1,000 ft^2): 170 tomato plants per 1,000 ft^2

Production expense	Unit	Quantity	Price	Labor (rate/hr)	Type†	Hours	Total cost ($)
Soil preparation							
Soil test	Complete tunnel		7.50	10.00	M	0.5	12.50
Major tillage			4.00	10.00	M		9.00
Rototill			2.00	10.00	M		7.00
Compost	ton	1	35.00	10.00	M	1.0	45.00
Raised bed formation				10.00	M	3.0	30.00
Fertilizer and lime	lb	50	5.00	10.00	M	0.5	10.00
Plastic mulch	linear ft	300	5.00	10.00	M	1.5	20.00
Irrigation drip tape	linear ft	300	5.00	10.00	M	0.5	10.00
Plant costs							
Transplants (including seed)		170 plants	26.00	10.00	M	1.5	41.00
Starter solution	lb		1.00				1.00
Production costs							
Herbicide	*not applicable*						
Insecticide			6.50	10.00	M	1.0	16.50
Fungicide			7.00	10.00	M	1.0	17.00
Cultivation	*not applicable*						
Irrigation/fertigation		1,000 ft^3	37.00	10.00	M	5.0	87.00
Twine and pruning				10.00	M	3.0	31.00
Fuel and oil							1.50
Plastic, stake removal				10.00	M	3.0	30.00
Row covers				10.00	M	1.0	10.00
Stakes				10.00	M	2.0	20.00
Wire hoops				10.00	M	1.00	10.00
Temperature management				10.00	M	10.00	100.00
Harvesting costs							
Picking				6.00	H	20.00	120.00
Postharvest costs							
Boxes		85	85.00				85.00
Grading				6.00	H	20.00	120.00
Marketing costs							
Packaging/delivery				10.00		10.00	100.00
Total production costs							**933.50**
Total fixed costs (from Table 8)							**155.25**
Total costs							**$1,088.75**

†M = Manager labor; H = Hired labor See notes for Table 7, page 24.

Notes for Table 7.

Production expense	Comments
Soil preparation	
Soil Test	Contact your local university soil testing laboratory for analysis.
Major tillage	Remove old crop residue (including roots) and till the soil.
Rototill	
Compost	Have compost tested for pH and soluble salts.
Raised bed formation	Make a raised bed 6–10 inches high.
Fertilizer and lime	
Plastic mulch	Use 1–1.25 mil embossed plastic mulch.
Irrigation drip tape	Use 8–10 mil drip tape with 4- to 12-inch drippers. Consider recycling drip tape.
Seeding or transplanting	
Seeds	See seed supplier list, Appendix.
Transplants	Transplants should be stocky and 5–6 weeks old.
Starter solution	Use a soluble starter fertilizer such as 20-20-20 or 9-45-15.
Production costs	
Herbicide	No herbicides are needed within the high tunnel.
Insecticide	Scout plants near sidewalls and vents for insect invasion.
Fungicide	Scout plants and prevent buildup of humidity.
Cultivation	Very little cultivation is needed during tomato production.
Irrigation/fertigation	Use in-line filters and clean water.
Twine and pruning	In a 20' x 96' high tunnel, approximately 740 feet of twine is used per row of tomatoes.
Plastic, stake removal	Many crops that follow tomatoes (peppers) can be planted in the existing plastic mulch.
Row covers	Row covers are reusable for several years. Keep them clean.
Stakes	Metal rebar or wooden (pine) stakes. Approximately 160 stakes are needed for a 20' x 96' high tunnel.
Wire hoops	Wire hoops are 3/16 inch by 64–76 inches. Space hoops 2 feet apart.
Temperature management	Monitor temperature carefully. Frequent adjusting of vents and row covers is necessary during flowering in mid April.
Harvesting costs	
Picking	Two to three harvests per week will be necessary.
Postharvest costs	
Boxes	Use clean boxes.
Grading	
Marketing costs	
Packaging/delivery	

Table 8. Fixed costs.

Fixed costs High tunnel 2,000 ft²			
Item	**Cost**	**Years used**	**Yearly costs**
Land charge/rent	$100.00	NA²	$100.00
High tunnel material	3,000.00	10	300.00
Plastic covering	300.00	3	100.00
Shade cloth covering	220.00	10	22.00
Wire hoops	40.00	5	8.00
Row cover	20.00	5	4.00
Stakes	10.00	5	2.00
Interest on land and buildings	20.00	NA	20.00
Taxes on land and buildings	10.00	NA	10.00
Depreciation on machinery	10.00	10	10.00
Interest on machinery	10.00	NA	10.00
Depreciation on irrigation equipment	10.00	5	10.00
Interest on irrigation equipment	5.00	NA	5.00
Depreciation on packing building	10.00	10	10.00
Interest on packing building	5.00	NA	5.00
Insurance	5.00	NA	5.00
	Total fixed costs for each year		**$621.00†**
	Area portion for 1,000ft²		**0.50**
	Yearly portion used for tomatoes		**0.50**
Tomatoes total fixed costs			**$155.25**

† Note: Fixed costs are for a 2,000 ft² high tunnel.

Table 9. Income sensitivity. (Total revenue ($) per 1,000 ft² (170 plants))

Price/lb	Yield/plant (lb)		
	8	10	12
$1.00	$1,360	$1,700	$2,040
1.10	1,496	1,870	2,244
1.20	1,632	2,040	2,448
1.30	1,768	2,210	2,652
1.40	1,904	2,380	2,856
1.50	2,040	2,550	3,060
2.00	2,720	3,400	4,080
2.50	3,400	4,250	5,100
3.00	4,080	5,100	6,120

Appendix: Sources of Supply

Drip irrigation supplies

BWI
9831 Lackman Rd.
Lanexa, KS 66219
Phone: 800-662-5320

Chesmore Seed Co.
5030 Hwy 36
St. Joseph, MO 64507
Phone: 800-383-0865

DripWorks
Phone: 800-616-8321
Web:www.dripworksusa.com

Hummert International
4500 Earth City Expressway
Earth City, MO 63045
Phone: 800-325-3055
www.hummert.com

Irrigation-Mart, Inc.
3303 McDonald Ave, East
Ruston, LA 71270-7412
Phone: 800-729-7246
www.irrigation-mart.com

Morgan County Seeds
18761 Kelsay Rd.
Barnett, MO 65011-3009
Phone: (573) 378-2655

Netafim USA
5470 E. Home Ave.
Fresno, CA 93727
Phone: (888) 638-2346
www.netafim-usa.com

Nolt's Produce Supplies
152 N. Hershey Ave.
Leola, PA 17540
Phone: (717) 656-9764

Plastic Plumbing Products
2541 Link Rd.,
St. Louis, MO 63114
Phone: 800-369-7257

Queen Gil International
P.O. Box 26025
Jerusalem, Israel
Phone: 800-831-6889

Rain-Flo Irrigation
884 Center Church Rd.
East Earl, PA 17519
Phone: (717) 445-6976

Roberts Irrigation Products
700 Rancheros Dr.
San Marcos, CA 92069-3007
Phone: (760) 744-4511

Spring Brook Irrigation
11291 E. Lakewood Blvd.
Holland, MI 49424
Phone: (877) 396-1956
www.springbrookirrigation.com

T-Systems Intl.
7545 Carroll Rd.
San Diego, CA 92121
Phone: 800-765-1860
www.t-tape.com

Zimmerman Irrigation Inc.
TRICKLE-EEZ Co.
Michigan Office
4266 Hollywood Rd.
St. Joseph, MI 49085
Phone: 800-874-2553
www.trickl-eez.com

Tomato seed

AgriSales, Inc.,
P.O. Box 2060
Plant City, FL 33564
Phone: 813-477-1405
www.agrisales.com

Baker Creek Heirloom Seeds
2278 Baker Creek Rd.
Mansfield, MO 65704
Phone: (417) 924-8917
www.rareseeds.com

Burpee Seeds
300 Park Ave.
Warminster, PA 18974
Phone: 800-888-1447
www.burpees.com

Chesmore Seeds
5030 Hwy. 36
St. Joseph, MO 64507
Phone: 800-383-0865
www.chesmore.com

FedCo Seeds
P.O. Box 520
Waterville, ME 04903
Phone: (207) 873-7333
www.fedcoseeds.com

Harris Seeds
P.O. Box 22960
Rochester, NY 14692-2960
Phone: 800-544-7938
www.harrisseeds.com

Holmes Seed Co.,
2125 46th St. N.W.
Canton, OH 44709
Phone: 800-435-6077

Johnny's Selected Seeds
310 Foss Hill Rd.
Albion, ME 04910
Phone: 800-854-2580
www.johnnyseeds.com

Morgan County Seeds
18761 Kelsay Rd.
Barnett, MO 65011
Phone: 888-266-0014

Park Seeds
Cokesbury Rd.
Greenwood, SC 29647
Phone: 800-845-3366

Rupp Seeds Inc.,
17919 County Rd. B
Wauseon, OH 43567-9458
Phone: (419) 337-1841

Seed Savers Exchange
3076 N. Winn Rd.
Decorah, IA 52101
www.seedsavers.org

SeedWay
1225 Zeager Rd.
Elizabethtown, PA 17022
Phone: 800-952-7333
www.seedway.com

Siegers Seed Co.,
8265 Felch St.
Zeeland, MI 49464-9503
www.siegers.com

Stokes Seeds
Box 548
Buffalo, NY 14240-0548
Phone: 800-396-9238
www.stokeseeds.com

Tomato Grower's Supply
P.O. Box 2237
Fort Myers, FL 33902
Phone: 888-478-7333
www.tomatogrowers.com

Totally Tomatoes
P.O. Box 1626
Augusta, GA 30903
Phone: (803) 663-0016
www.totallytomato.com

Note: Mention or exclusion of any proprietary product or company does not imply endorsement by University of Missouri Extension.

High tunnels (hoophouses)

A. M. Leonard
P.O. Box 816
Piqua, OH 45356
Phone: 800-543-8955
www.amleo.com

Atlas Greenhouse Systems, Inc.
P.O. Box 558
Alapaha, GA 31622
Phone: 800-346-9902
www.AtlasGreenhouse.com
e-mail:
service@atlasgreenhouse.com

Conley's Greenhouse Mfg.
4344 Mission Blvd.
Montclair, CA 91763
Phone: 800-377-8441
www.conleys.com
e-mail: info@conleys.com

CropKing, Inc.,
5050 Greenwich Rd.,
Seville, OH 44273
Phone: (330) 769-2616
www.cropking.com
e-mail: cropking@cropking.com

FarmTek
1440 Field of Dreams Way
Dyersville, IA 52040
Phone: 800-327-6835
www.FarmTek.com

Grow-It Greenhouse
P.O. Box 26037
West Haven, CT 06516
Phone: 800-932-9344
www.growitgreenhouses.com

Harnois Greenhouses
www.harnois.com
US Distributors include:
Syngenta Inc./S&G Flowers (D)
5300 Katrine Ave.
Downers Grove, IL 60515
Tel: (630) 969-0889
1-(888) 323-7253
Fax: (630) 969-6498
dennis.meisch@syngenta.com

Ledgewood Farm
Edward Person
RFD 1 Box 375
Moultonboro, NH 03254
Phone: (603) 476-8829

Ludy Greenhouses
P.O. Box 141
New Madison, OH 45346
Phone: (937) 996-1921
www.ludy.com
e-mail: bmunchel@ludy.com

Poly-Tex Inc.,
P.O. Box 458
Castlerock, MN 55010
Phone: 800-852-3443
www.poly-tex.com

Rimol Greenhouse Systems
40 Londonderry Turnpike
Hooksett, NH 03106
Phone: (877) 746-6544
www.rimol.com

Speedling Inc.
P.O. Box 7238
Sun City, FL 33586
Phone: 800-881-4769
www.speedling.com

Stuppy Greenhouse Mfg.
1212 Clay St.
P.O. Box 12456
North Kansas City, MO 64116
Phone: 800-733-5025
www.stuppyg.com
e-mail: greenhouse@stuppy.com

Turner Greenhouses
P.O. Box 1260
Goldsboro, NC 27530
Phone: 800-672-4770
www.turnergreenhouses.com

Zimmerman's Welding
Jacob L. Zimmerman
16645 Ridgewood Rd.
Versailles, MO 65084
Phone: (573) 378-4770

Biological pest controls

Alternative
349 East 86th St., Suite 259
Indianapolis, IN 46240
Phone: (317) 823-0432

Arbico
P.O. Box 4247CRB
Tuscon, AZ 85738
Phone: (602) 825-9785

Associates Insectary
P.O. Box 969
Santa Paula, CA 93060
Phone: (805) 933-1301

Hummert International
4500 Earth City Expressway
Earth City, MO 63045
Phone: 800-325-3055

Hydro-Gardens, Inc.,
P.O. Box 25845
Colorado Springs, CO 80936-5845
Phone: 800-634-6362

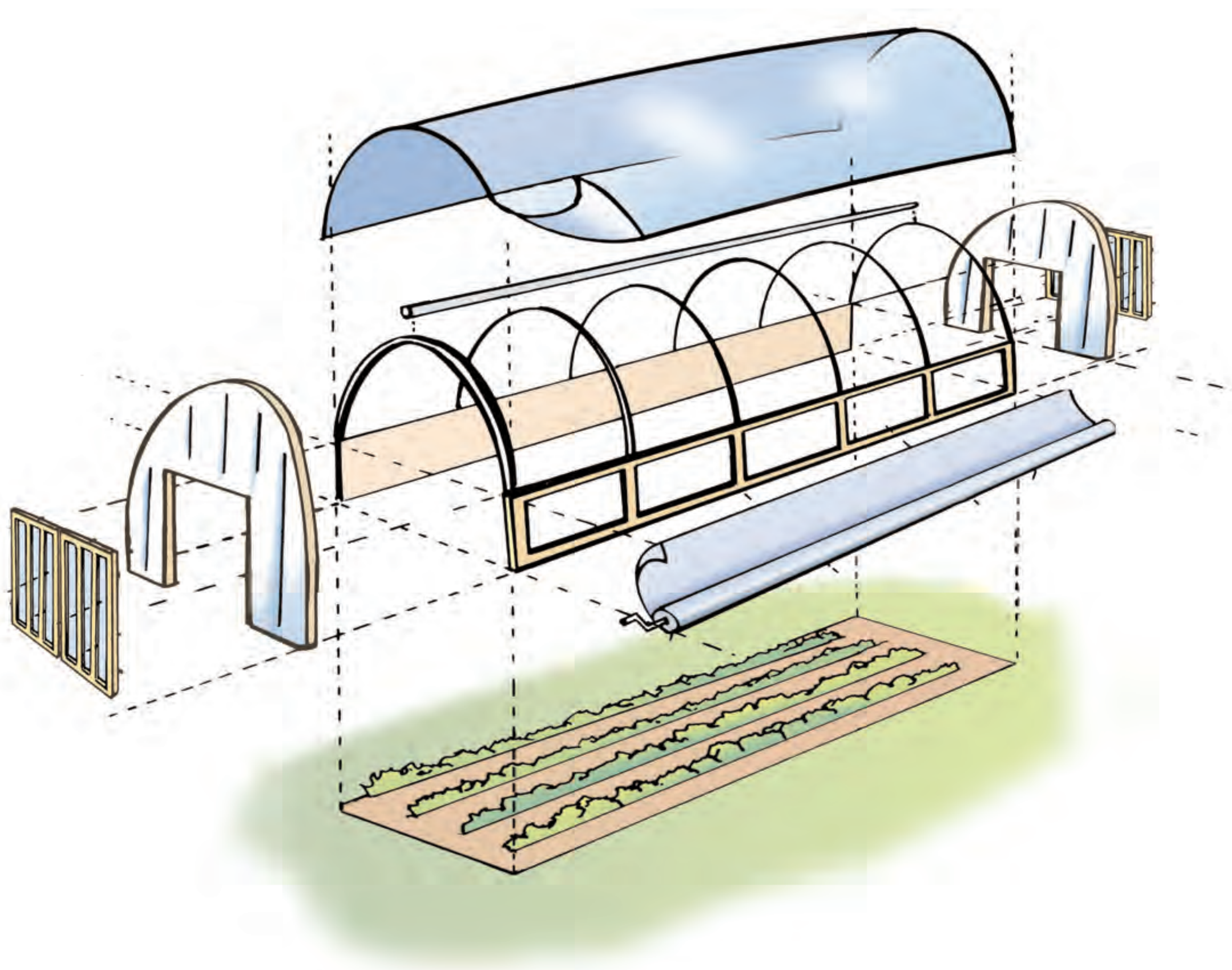
IPM Laboratories, Inc.,
Locke, NY 13092-0300
Phone: (315) 497-2063

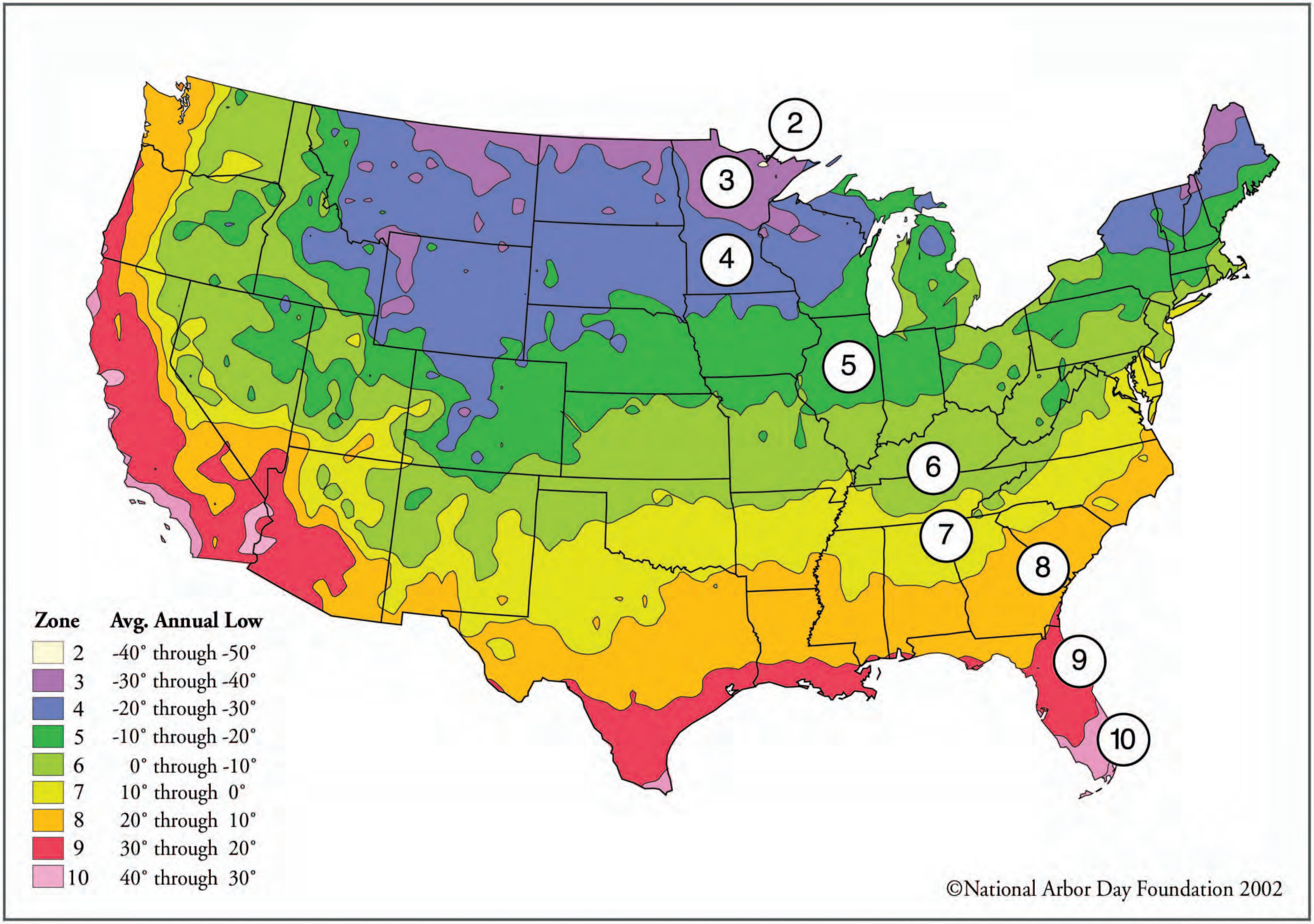
Koppert Biological Systems, Inc.,
28465 Beverly Rd.
Romulus, MI 48174
Phone: (734) 641-3763

Plant Products Co.,
6160 Riverside Dr.
Suite 103
Dublin, OH 43017
Phone: 800-565-4769

The Green Spot, Ltd.,
93 Priest Rd.
Nottingham, NH 03290-6204
Phone: (603) 942-8925

Westbridge Agricultural Products
1150 Joshua Way
Vista, CA 92081
Phone: 800-876-2767





2002 Arborday.org Hardiness Zones map, based on the 1990 USDA hardiness zone map.
Source: National Arbor Day Foundation, Arborday.org.

M170 New 3/04/3M