IOWA STATE UNIVERSITY
University Extension

Iowa High Tunnel Fruit and Vegetable Production Manual

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This project is supported by a competitive grant from the Marketing and Food Systems Initiative of the Leopold Center for Sustainable Agriculture. For more information, go to www.leopold.iastate.edu, or call (515) 294-3711.

Iowa High Tunnel
Fruit and Vegetable Production Manual

High tunnels are valuable assets to growers enabling them to produce high yields of quality horticultural crops. However, different strategies and more detailed management are required with this method of production. The objective of this workbook is to provide growers with the information and resources to use high tunnels effectively, enhance productivity and net income, and learn from the experience of other high tunnel users.

This educational resource for Iowa fruit and vegetable growers is a tribute to Dr. Henry (Hank) Taber, ISU Extension Vegetable Specialist. He was a pioneer in agricultural plastics research and high tunnel production. For over 30 years he shared his expertise and experience with vegetable growers and students in Iowa and across the country.

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Contents

Introduction to High Tunnels

By Linda Naeve
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Objectives:
You will:
- Recognize the difference between a high tunnel and a greenhouse structure.
- Identify the advantages of high tunnels.
- Identify limitations to their use.

Definition

Although they resemble greenhouses, high tunnels, also referred to as "hoop houses," are quite different. High tunnels are simple, plastic-covered, passive-solar-heated structures in which crops are grown in the ground (Figure 1). Typically, they are ventilated by manually rolling the sides up or down as needed. They are designed to extend the growing season and intensify production.

Figure 1. High tunnels are simple, plastic covered, passive-solar-heated structures.

High tunnel production facilitates the diversification of farming operations, requires less capital expenditure than greenhouse production, and for relatively low investment, often yields high returns. Unlike commercial greenhouses that may cost $20 per square foot or more, depending on the covering, high tunnels cost as little as $3 to $5 per square foot, depending on the size, covering, frame material and end wall construction (Spaw et al. 2004). For the purposes of property assessment and taxation, high tunnels are usually classified as temporary agricultural structures because they lack a concrete foundation or footings and are moveable.

High tunnels are used by the horticulture industry to extend the harvest season of many high-value crops. Because they are primarily used in Iowa for early season production, they are like row covers. However, high tunnels are larger and taller, allowing room for the crop to grow to maturity, cultural practices to be performed and equipment to be operated under them, such as tilling and laying plastic (Figure 2). Thus, the descriptive name -"high tunnel." High tunnels and row covers also differ in the length of time they are left in place; row covers are often removed before the end of the season, and high tunnels may remain in the same place for several cropping seasons before being moved.

Figure 2. High tunnels enable equipment, such as this tractor and plastic layer, to operate under them.

High tunnels have been extensively used for several years in many regions of the world where the growing season is short or the climate is not conducive to the production of quality fruits, vegetables, herbs and flowers. China and Spain currently have the largest concentration of high tunnels. They were not widely used in the United States until the last decade, when an increasing number of farmers began using them to enhance their existing production system and increase marketing opportunities.

Existing fruit and vegetable growers add high tunnels to their operations to increase marketing opportunities. High tunnels help growers extend the season on both ends and provide a steady supply of fruits, vegetables and cut flowers for the market. High tunnel production requires a combination of cultural practices unique to high tunnels and typical of field production, such as proper variety selection (adaptable varieties for early and main season) and sequence of planting dates (Taber et al. 2006).

Figure 3. The altered soil temperature and climate in a high tunnel extends the growing season of crops.

Advantages

High tunnel production is considerably different from field production. More detailed attention is required on water and nutrient management, temperature control, crop selection and continuous production strategies. The advantages of growing crops in high tunnels rather than in fields are:

- Extended seasons.
- Weather protection.
- Labor efficiency.
- Environmental control.
- Reduced incidence of plant diseases.
- Improved quality.
- Increased revenue per square foot.

Extended Seasons

High tunnel growers say that the environment in the high tunnel is one hardiness zone warmer than the field. The altered soil temperature and climate in a high tunnel extends the growing season of crops, enabling them to be planted earlier in the spring and to produce a crop later in the fall (Figure 3). As a result, they are able to receive a premium price for their out-of-season produce. The primary crops grown in a high tunnel are high-value fruits and vegetables, such as tomatoes, peppers, melons, strawberries and raspberries. Growers extend the growing season into late fall and winter by growing leafy greens, which can tolerate cooler temperatures and the reduced day length and light levels.

Weather Protection

High tunnels protect the growing crop from environmental stresses, such as drought, driving rain, hail, wind and temperature extremes.

Labor Efficiency

Since it is a covered structure, workers can perform most tasks, such as planting, pruning, trellising, pest control and harvest without being affected by the weather. With the potential for several production seasons, high tunnels create an opportunity for year-round employment positions. However, high tunnels do require higher labor inputs in order to achieve maximum production, such as raising and lowering the sides several times a day.

Environmental Control
Growers have more control over growing conditions and the environment. They can control the water, fertility, and to some extent, the temperature. As a result, greater yields of quality produce can be harvested. The continuously dry environment with drip irrigation for the crops reduces weed growth in the high tunnel.

Reduced Incidence of Plant Diseases
Compared to field production, the need for disease, weed and wildlife management is reduced in a high tunnel, minimizing pesticide inputs. The lack of water on the foliage significantly reduces the incidence of foliar diseases, such as septoria and early blights on tomatoes.

Improved Quality
Due to the protected microclimate, crops produced in well-managed high tunnels tend to be of higher quality and produce higher yields than field-grown crops. Also, greater shelf-life of leafy greens and raspberries have been reported.

Increased Revenue per Square Foot
The bottom line is the potential for increased revenue. This may be the result of higher premiums received for out-of-season crops, increased quality and yield, the value in the marketplace (organic or reduced pesticide use) and reduced cost of inputs. Of course, net income may be adversely affected depending on the crop grown and management skills of the grower.

Table 1. Construction costs for a 26 ft x 48 ft high tunnel at Blue Gate Farm near Chariton, Iowa. Winter, 2009.

Description	Cost[1]	Notes
High tunnel kit purchased from FarmTek	$3,126	Included shipping
Lumber (cedar)	$618	Baseboards, ribbon boards, and endwall framing
Cement	$100	For footings to anchor rib posts
Tile	$64	For drainage around the high tunnel
Hardware	$145	End walls, ribbon board, etc.
Storm door	$98	Installed in endwall
Misc. materials	$94	Vent fan shutter, electrical
Total	**$4,366**	

From: *The Practical Farmer Newsletter*, Summer, 2009.
[1]Does not include land preparation, utility installation and labor.

Challenges
When considering high tunnel production, however, growers should look at the whole picture. Producing a crop in a high tunnel is typically more costly than growing it in the field, due to the structure's capital costs and increased manual labor requirements. Other considerations include:

- Initial cost and maintenance.
- Different pest problems.
- Regular monitoring and labor.
- Crop rotation.

Initial Cost and Maintenance
The high cost of high tunnels requires a multi-year payback period. According to Adam Montri, Outreach Coordinator for the Michigan State University Student Organic Farm, barring a tornado or other severe weather, a galvanized metal high tunnel frame should last at least 30 to 40 years. However, the polyethylene covering will need replacing every four or five years if not before. Even though a covering may not appear damaged, the light levels in the high tunnels diminish considerably after a few years, reducing crop growth and productivity. In addition, while the plastic covering used on high tunnels is durable, it is vulnerable to severe wind and storm damage. Baseboards, hipboards and end-walls constructed of wood may need changing because they rot over time.

> "I think there is potential to pay back a high tunnel in one to two years but that depends on farmer experience, market access and consumer willingness to pay premium prices in the winter as well as having an awareness of local produce in the winter months."
>
> "Those numbers work if the high tunnel is isolated by itself on the farm books and if all net income from the house goes back to paying for the high tunnel. However, the reality of any business is that there are additional costs above and beyond, which in this case would be electric and water to the site, seed purchases, specific/ additional tool purchases, fertility inputs/ management, harvesting and storage requirements. These costs clearly increase the amount of capital that goes into the total high tunnel."
>
> *---Adam Montri, Outreach Coordinator, Michigan State University Organic Farm*

Different Pest Problems
Although there are fewer disease problems, there tends to be increased insect pressure. The high tunnel creates a favorable environment for insect pests that are typically not seen in the field or are not an annual problem, such as tomato hornworm, cutworm, thrips, mites, and aphids.

Regular Monitoring and Labor
High tunnels must be closely monitored to control the climate, especially in the spring and fall, when the temperatures in a closed high tunnel can quickly rise to harmful levels for crops. Additional investments in electrical installation and thermostatically controlled side and overhead ventilation will reduce the need for frequent monitoring.

Crop Rotation
The limited space in a high tunnel makes crop rotation difficult when a single crop, such as tomatoes, are grown for several consecutive years. To avoid losing their crop to soil-borne diseases, some tomato growers are planting grafted tomatoes for increased resistance to soil-borne pathogens. Grafted plants, however, are considerably more expensive than tomato seedlings (O'Connell 2008).

Economics
Since it often costs more to produce a crop in a high tunnel than in the field, growers must carefully chose what crops or combination of crops will yield the highest return. Not all crops are economical to produce in a high tunnel. When determining what to produce in a high tunnel, growers need to look closely at the value of the crop, length of its growing season, labor required for production, the yield of the crop, and the potential market price. Not all crops are high value and productive enough to justify the expense of the high tunnel. Although several crops can be grown successfully in high tunnels, experienced growers in Iowa found that tomatoes, brambles (raspberries and blackberries) and strawberries were the most profitable (see Table 2 and Table 4 on pages 8 and 9).

More information on financing and marketing can be found in a later chapter.

In Appendix I (page 87), read about two farmers in the Northeast who incorporated high tunnel cropping systems into their farming operations. Compare the enterprise budgets for their high tunnels. Use this information to begin developing your budget.

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O'Connell, Suzanne. 2008. Grafted Tomato Performance in Organic Production Systems: Nutrient Uptake, Plant Growth, and Fruit Yield. Thesis. North Carolina State University. Available online at: http://www.lib.ncsu.edu/theses/available/etd-11072008-152636/unrestricted/etd.pdf

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Taber, Henry G. and James Kubik. 2008. High Tunnel Construction Considerations. Iowa State University Horticulture Department.
Available online at: http://www.public.iastate.edu/~taber/Extension/Second.htm

Table 1. Summary of initial capital investment for a 30 ft x 96 ft high tunnel.[1]

Item	$/Tunnel
Pre-plant costs	$120
Tunnel construction costs (tunnel, automated sides, ends, labor) (2009 prices)	$8,000
Irrigation supplies/equipment	$230
Stakes and twine	$250
Total[2]	**$8,600**

[1]Adapted from Heidenreich, Cathy, Marvin Pritts, Mary Jo Kelly and Kathy Demchak. High Tunnel Raspberries and Blackberries. Cornell University, Ithaca, NY. 2008 rev.
[2]Does not include land, insurance, tools, equipment, interest, etc. (expected life - 10 years).

Table 2. Tomato production in a 30 ft x 96 ft high tunnel.[1]

Item	Quantity, hr	$/Tunnel
Labor ($10/hour)		
Cover tunnel	6	$60
Retighten cover	4	$40
Soil preparation and planting	12	$120
Scouting and pesticide application	8	$80
Maintenance (stake, weed, prune, etc.)	35	$350
Monitor and ventilation	8	$80
Harvest, grading and packaging	50	$500
Post-season cleanup	6	$60
Supplies/Materials		
Fertilizer		$35
Plastic mulch		$18
Transplants (including seed)	360	$75
Fuel and electrical		$25
Pesticides		$25
Lab testing		$30
Harvest supplies		$500
Scouting supplies		$50
Water ($4.90/1,000 gallons)	15,000 gallons	$74
1/10 of initial high tunnel costs		$860
Total estimated expenses[2]		**$2,982**
Gross income with an estimated yield of 5,200 pounds marketable ($2/pound)		$10,336
Less production expenses		$2,982
Net income		**$7,354**

[1]Taber, Henry G., Bernard Havlovic and Nick Howell. 2007. High Tunnel Tomato Production. 2007 ISU Outlying Research Farms Report.
[2]Does not include costs associated with marketing.

Table 3. Summary of initial capital investment for raspberry production in a 30 ft x 90 ft high tunnel.[1]

Item	$/Tunnel
Pre-plant costs	$120
Tunnel construction costs (tunnel, automated sides, ends, labor) (2009 prices)	$8,000
Plants	$357
Planting	$375
Irrigation	$230
Trellis	$557
Total[2]	**$9,264**

[1]Adapted from Heidenreich, Cathy, Marvin Pritts, Mary Jo Kelly and Kathy Demchak. High Tunnel Raspberries and Blackberries. Cornell University, Ithaca, NY. 2008 rev.
[2]Does not include land, insurance, tools, equipment, interest, etc.

Table 4. Raspberry ('Autumn Bliss') production in a 30 ft x 90 ft high tunnel.[1]

Item	Quantity, hr	$/Tunnel
Labor ($10/hour)		
Cover tunnel	6	$60
Retighten cover	4	$40
Scouting and pesticide application	4	$40
Prune and train canes	8	$80
Narrow rows	6	$60
Maintenance	9	$90
Monitor and ventilation	8	$80
Harvest and packaging	51	$510
Supplies/Materials		
Fertilizer		$5
Pesticides		$25
Lab testing		$30
Harvest supplies		$1,000
Scouting supplies		$50
Water ($4.90/1,000 gallons)	15,000 gallons	$75
1/10th of initial investment		$926
Total estimated expenses[2]		**$3,071**
Gross income with an estimated yield of 1,440 pounds marketable ($6/pound)		$8,640
Less production expenses		$3,071
Net income		**$5,569**

[1]Domoto, Paul, Gail Nonnecke, Bernie Havlovic, Leah Riesselman, Dave Breach, Nick Howell and Sabina Quint. 2008. High Tunnel Bramble Production. ISU Outlying Research Farm Report.

Site Selection

By Eldon Everhart
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Objectives:
You will be able to:

- Determine the best location on your property for a high tunnel after evaluating the soil, drainage, wind, and light exposure of the site.
- Identify the deficiencies in specific sites and how they can be corrected.

A high tunnel should be located where it can be easily accessed and where water and electricity (if desired) can be supplied at a reasonable cost. A well-drained site in full sun and with protection from the wind is best.

Orientation

Orientation of high tunnels is often a matter of convenience or personal preference. Good production has been obtained with either east-west or north-south orientation. Also consider the months that a crop will be growing in the high tunnel. If crops will be grown during the low light period of winter, an east-west orientation will maximize sunlight. Solar gains in a high tunnel are greatest when solar radiation strikes the cover at a 90 degree angle. During the winter and early spring, an east-west orientation more effectively captures solar radiation. Also, a gothic-shaped structure captures this incoming radiation in the winter months better than a Quonset structure.

Figure 1. The preferred orientation can depend on the amount of prevailing wind and the height of the crops that will be grown in the high tunnel.

Figure 2. A good site is level, well-drained, fertility built up, sod destroyed, plowed and windbreak to the north (Taber and Kubik 2008).

Terrain

If possible, problems with terrain should be corrected before construction begins. If terrain problems cannot be corrected, then it may be best to choose a different site.

Sites that flood or have a high water table should be avoided. A site with about a 5-percent slope will ensure good air flow and surface drainage, but high tunnels can be built on flat or steeper sites.

The location should be slightly higher than the surrounding area so water will not drain into the high tunnel or flow through it if heavy rains occur. Ideally, the tunnel should be at least a foot above grade of the land around it. The area inside the high tunnel should be flat so that tillage and other tasks, such as bed making, are easier and irrigation is more uniform.

Runoff from a high tunnel roof and from rain and melting snow can be significant. For example, an inch of rain falling on a 30 foot x 96 foot house equals 0.6 gallons per square foot, or 1,728 gallons over the entire structure (Blomgren, et al. 2007). Rain water from the roof should be diverted with a swale around the high tunnel. Runoff from uphill should be diverted before it reaches the high tunnel.

In addition to surface water, subterranean water and seasonal springs must be avoided or properly dealt with. In some cases, it may be necessary to install drainage tile in the soil under the high tunnel. Excessive ground water or wet soils often lead to soil-borne disease problems, secondary insect infestations, nutritional problems and heat loss.

Light

Everything else being equal, a north-south orientation is probably best for optimum sun exposure and less crop shading, particularly with close row spacing and the use of a trellis system that results in tall plants. A north-south orientation will warm up more quickly on a sunny morning, but high tunnels typically have to be opened by 9:00 a.m. anyway, because they very quickly become too hot.

Wind

An ideal high tunnel site allows the free flow of air in summer and provides protection from cold winds in winter and from strong winds in summer. It is usually best to avoid building on hill tops and in frost pockets. A windbreak on the windward side of the tunnel may help to reduce the effect of strong winds. When strong winds do occur, the vents and doors on high tunnels should be closed, especially on the windward side.

Figure 3. A windbreak can prevent serious damage caused by strong winds.

Since most strong winds In Iowa come from the southwest or northwest, a windbreak on the north or west side of the high tunnel will provide protection. A deciduous windbreak on the west side will provide wind protection and slight shade from hot afternoon sun during the summer. In the fall, the deciduous windbreak will lose its leaves, creating less shade when the sun angle is lower and more heat is needed in the tunnel. Since some light air movement is desirable in the high tunnel to assist with pollination, a deciduous windbreak, which allows more wind through than an evergreen windbreak, is preferable.

Soil

Good internal soil water drainage is very important. All of the water will have to be provided by irrigation.

Lighter textured soils like sandy loams or loamy sands are most desirable because they will warm up more quickly in the spring, are easily worked, provide a good media for root development, and respond more readily to irrigation and fertilizer applications.

Clay soils do not drain well, remain colder longer, are more prone to the buildup of salts and increase the chance of soil-borne disease problems. Although growers can amend and improve clay soils, it may be best to choose a different site if the soil has a high clay content. You can determine your site soil type by consulting the county soil survey. Go to the USDA Natural Resources Conservation Service Web Soil Survey at: websoilsurvey.nrcs.usda.gov/app/HomePage.htm.

When the soil in a location is repeatedly used over a number of years, organic matter must be returned to the soil. This requirement is especially true of high tunnels. With their intense management and heavy crop nutrient use, high tunnel production systems deplete soil organic matter more quickly than traditional field production systems. In addition, crop residue from high tunnel crops should not be incorporated back into the soil because of the potential for diseases and for insects.

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Available online at: public.iastate.edu/~taber/Extension/Second.htm

Soil Management and Fertility

By Henry G. Taber
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<u>Objectives:</u>
You will:

- Learn about the soil's physical and chemical properties and how they affect nutrient management.
- Be able to calculate the fertilizer needs in a high tunnel based on soil test recommendations.
- Learn about characteristics of compost and what affects the decomposition rate.
- Become familiar with salinity issues associated with high tunnel production.

Site location is a key component for high tunnel vegetable production – sunlight, drainage and wind protection. Some may disagree with the following observation, but soil type is of less importance because crops can be grown in modified raised beds and soilless media. However, let us assume the structure is moveable and soil management is a key consideration.

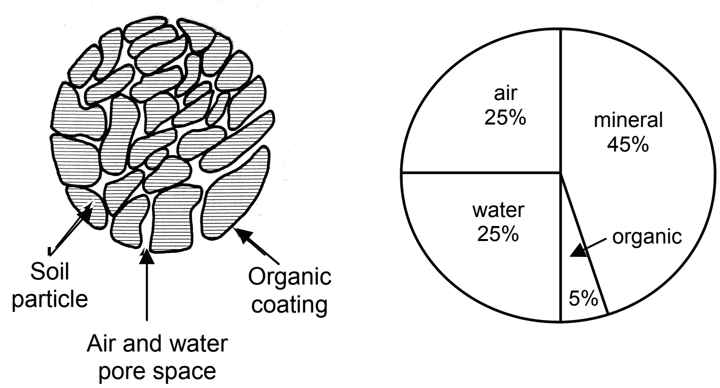


Figure 1. Cross section of a soil core showing the composition and arrangement of the components.

The importance of soil is to anchor the plant in place, provide water and some needed plant nutrients, and oxygen (air) for root growth. The major components of soil are its physical and chemical properties plus air and water. The physical components include the individual particles, size (texture) and their arrangement (structure); and the organic matter that provides the 'glue' to hold the particles together (Figure 1).

Physical Properties

Soil texture (or particle size) refers to sand, silt and clay. (Organic matter and gravel are ignored). Why is texture important? Consider the characteristics of soils with different textures.

Soil Particle Sizes
Sand = 2 mm to 0.05 mm
Silt = 0.05 to 0.002 mm
Clay = less than 0.002 mm

<u>Characteristics of a high clay content soil:</u>

- High water-holding ability.
- High cation exchange capacity (holds nutrients as Ca, K, Mg, micronutrients, etc.).
- Low infiltration rate (rain or overhead irrigation water runs off).
- Warms up slowly in the spring.
- Resists change to pH (high buffering capacity means more lime is needed to make a change).

Characteristics of a high sand content soil are:

- Low water-holding capacity.
- Some nutrients are prone to leaching.
- Warms up quickly in the spring.
- Shows a rapid change in pH.

Because of its characteristics, a soil test is needed about every 1 to 2 years for a sand or sandy loam soil, but only every 4 years is necessary for a soil with higher clay content.

A **'loam' soil** that has less than 28 percent clay content is considered ideal, but silt loams are also quite acceptable. A special soil type that is not found widely in Iowa is known as organic or muck (some are located in north central Iowa near Clear Lake and Fertile). These soils contain high amounts of organic matter, many greater than 90 percent. By definition a muck soil contains 25 percent or more organic matter. They are excellent for vegetable root crops but not adapted to high tunnel production because of location in a depression of the landscape (frost) and looseness (anchoring the tunnel is a problem).

Thus, a good location for the high tunnel from the soil standpoint is a well-drained loam soil with high organic matter (greater than 3%), and a pH of 6.5 on the upper part of the land-scape with a northwest windbreak. We can adjust the pH with agricultural limestone and improve the organic matter with the use of compost. How to locate a good site? Use your local county soil survey maps or go online at the USDA Natural Resources Conservation Service site at: websoilsurvey.nrcs.usda.gov/app/

Chemical Properties (plant nutrients)

Only 17 elements are needed by plants to achieve top production and fruit quality. Of these, carbon (C), hydrogen (H) and oxygen (O) come from the air or water and are never limiting. The remaining 14 may or may not be in adequate amounts, depending on the soil type and soil pH. First, a definition of pH – potential acidity. A neutral value is 7.0, meaning there is an equal concentration of H^+ and hydroxyl (OH^-) ions in the soil solution or soil water. Most Iowa soils are neutral or slightly alkaline. A soil pH above 7.1 is alkaline or basic, the OH^- ions outnumber the H^+ ions. When the reverse is true, the soil pH is acidic or has a pH less than 7.0. Most vegetables do well in a slightly acid soil with a pH 6.2 to 6.8. Within this range root growth, plant vigor, nutrient availability and microbial activity are optimal. Beyond this range, plant growth can be severely limited because required nutrients are unavailable and soil microbes work less effectively.

Which nutrients are likely to be deficient or in excess?

- **Nitrogen (N), phosphorus (P)** and **potassium (K)** are added to the soil with commercial fertilizer or added compost.

- **Calcium (Ca)** and **magnesium (Mg)** are no problem in the upper Midwest. They typically leach out of sandy soils. They are replaced with lime applications, particularly dolomitic lime (lime that contains at least 10% Mg). However, do not apply dolomitic lime unless the soil test calls for it because high soil Mg restricts K uptake.

- **Sulfur (S), nickel (Ni)** and **chlorine (Cl)** are naturally available (organic matter).

- **Copper (Cu), manganese (Mn), boron (B) and iron (Fe)** are generally available in sufficient quantities. An exception is Cu on organic soils.

- **Zinc (Zn)** is a problem in some areas of Iowa (northwest) because of high soil pH. You should ask for Zn determination on the soil test report. There is adequate Zn if the Zn value is greater than 0.75 ppm.

- **Molybdenum (Mo)** is greatly influenced by soil pH (the higher soil pH, the more Mo available), Mo deficiency is generally not a problem for Iowa soils.

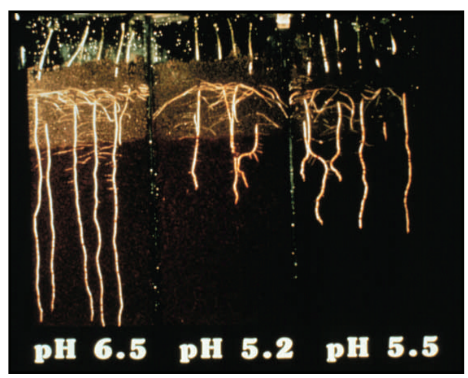
The best way to determine if the above mentioned essential plant nutrients are adequate is to take a soil test. Ask for P, K, Ca, Mg and Zn. There has never been a deficiency of Ni, Cl or S.

For the micronutrients, a plant analysis during the growing season is preferred. Obtain a copy of FG-605, Micronutrient Characteristics with Emphasis on Vegetable Crops. A list of plant analysis laboratories can be found in Appendix E on page 81.

pH and Lime Recommendation

The single most important soil amendment factor that you can do is make sure the soil pH is adequate. Most vegetables do well at a pH range of 6.2 to 6.8, but some crops can stretch the range from 5.7 to 7.4. Nonetheless, you will derive more beneficial effect from improving pH, if low, to 6.5 than adding other fertilizer elements. Low pH occurs where heavy N rates have been used in the past and/or on sandy loam or coarser textured soils where the bases, such as Mg, Ca, and K, have been leached such as in the Eastern part of the state along the rivers.

Figure 2. Effect of soil pH on shoot and root growth. Muskmelon needs a soil pH of 6.8, as shown in the plot at the back of photo. The front plot has a soil pH of 5.5.



Note stunting of root growth as the result of high H^+ ions (low pH).

Lime Sources

1. Ground limestone (95% of liming materials). The two types are:
   - Calcite ($CaCO_3$) is dominant, Mg is low to medium
   - Dolomitic [$CaMg(CO_3)_2$] is dominant; Mg is high (greater than 10%)

2. Others
   - Calcium oxide (CaO) – burned, lump, quick reacting
   - Calcium hydroxide ($Ca(OH)_2$); slaked, hydrated, quick reacting

Be sure to use agricultural limestone because state law requires certification – based on its effective calcium carbonate equivalency and fineness. Apply well in advance of the growing season – in the fall before the tunnel is constructed on the site. If you find that the pH is low just prior to planting in the spring, consider using the hydrated or slaked lime for a quick reaction. These products can be obtained from most lumber companies.

Be careful, do not over apply lime. Detrimental effects of over liming are:
- Change in pH, which is detrimental to plant growth.
- Decrease in availability of P.
- Deficiencies in Fe, Mn, Zn and, to some extent, Cu.
- Reduced root uptake of B.

Nitrogen is usually not reported on the soil test report east of the Missouri river because the higher rainfall, and unpredictably of rain events makes a soil N test meaningless. An exception is the spring sidedress N test done for commercial field corn. Nitrogen requirement is based on previous cropping history of the field and current crop needs. In some plant families there is a big difference in need, i.e., consider the Solanaceae or nightshade family (tomatoes, peppers and eggplant).

Effect of a high N soil application

Tomato - low yield and delay in harvest from excess N. Generally, 70 lbs N /acre or more

Pepper - high response; rates are equivalent to field corn or 150 lbs N/acre

However, the high tunnel is a desert-like condition and a soil N test would be a suitable indicator of soil N status, particularly with compost addition. More research is needed in this area.

What do numbers mean on the fertilizer bag?

How to calculate your needs? (see fertilizer application worksheets, Appendix A1 and A2.)

Be careful, do not purchase what you do not need. Below are a few examples.

Gypsum ($CaSO_4$). Oxygen and sulfur are supplied by air and organic matter. Calcium is supplied by lime or you do not need it if the soil pH is 6.2 to 6.8. Gypsum is mainly used as a soil conditioner by homeowners.

Chelated Ca or other soluble elemental products, recommended as a foliar spray to improve fruit quality. It is frequently sold for blossom end-rot control in tomatoes. The problem is not the Ca supply, but rather infrequent irrigation practices.

There are many other products on the market with dubious claims.

Organic Matter

Soil organic matter consists of or is derived from:

decomposition of organic residues
+
excretions from microorganisms and microbial cells.

The end product is called **humus**, the more or less stable fraction of the soil organic matter remaining after the major portion of the added plant and animal residues have decomposed. The organic matter fraction of soil is small (1-6%) compared to clay content of soils.

Special fertilizer mixes for special crop needs
Starter fertilizers high in P - Use for early spring (cold soils) transplants, especially tomatoes and peppers.
$Ca(NO_3)_2$ - side-dressed N source for peppers, tomatoes, muskmelons.
KNO_3 - high purity for greenhouse production.

Three major reactions occur when fresh, organic tissue is added to a well-aerated soil. Carbon is oxidized by the soil microorganisms to produce carbon dioxide, water, energy and biomass (humus). Nitrogen, P and S are released/immobilized by the microbe population. Compounds that are very resistant to microbial action are formed, such as lignin, which is a very large complex consisting of hundreds of inter linked phenolic rings with various methyl groups attached. They are difficult for the microbes to breakdown.

Decomposition rate of organic matter depends on:

- *Environmental conditions*, such as moisture, temperature and soil texture.
- *Particle size of organic material*. Smaller results in faster decomposition because of more surface area (i.e., twigs versus branches. Whole leaves versus grinding, which destroys the waxy outer coating, breaks up the ligneous cell walls).
- *Cultivation frequency.* Cultivation disrupts soil aggregate structure.
- *Depth of tillage.* Tilling close to the soil surface results in slower decomposition; Incorporated organic matter decomposes faster. (the soil is moist and contains more soil microorganisms at a greater depth).
- *Irrigation.* Good soil moisture favors rapid decomposition but also increases production of dry matter.
- *Type of organic matter.* Materials rich in N, such as green and animal manures, decompose more quickly.
- *Crop rotation.* An extensive root system has a higher C:N ratio.

The benefits of adding organic matter to the soil are:

- Provides a nutrient reservoir for N, P and S.
- Retains nutrients in an available form - humus molecules have pH-dependent charges that hold positive ions.
- Increases aggregate formation - the crumb-like structure that gives soil 'tilth', or the glue
- Increases soil porosity - changes the physical characteristics of the soil; alters water retention and water infiltration.

Over half of the P and almost all of the S in soils is in the organic matter. However, the rate of release is not necessarily even. A 60-year experiment of release of N-P-S from organic matter found that 30 percent of the C-N-S was mineralized (Organic matter dropped 30%), but only 17 percent of the P compounds were mineralized.

Why is the carbon:nitrogen (C:N) ratio of organic residues important?

- Competition among microorganisms for the N
- C:N determines the rate of decay - rate at which the N is made available to plants.
- C in plant dry matter is approximately 42 percent
- C in soil organic matter is approximately 50 percent (40 to 58%, the 58% in stable humus in sub-soil)

The C:N in bacteria/fungi is much less than plant materials and less variable. Cultivated soils range from 8:1 to 15:1, or approximately 12:1. The ratio is lower in the subsoil containing the stable humus.

For example, corn stalks have a 60:1 (C:N). If 1/3 of the carbon remains in the soil, then a 20:1 ratio is left. Microbes need a 10:1 ratio and will take N from soil to satisfy the 10:1. Thus, the addition of corn stalks requires additional N to aid in decomposition without resulting in a soil N loss.

Figure 3. Yard waste decomposition at a wind-rowed compost site.

Table 1. Carbon:nitrogen (C:N) ratio of various organic materials.

Material	%C	%N	C:N
Spruce sawdust	50	0.05	600
Hardwood sawdust	46	0.10	400
Wheat straw	38	0.50	80
Corn stover	40	0.70	57
Bluegrass clippings	37	1.2	31
Rye cover crop	40	1.5	26
Young alfalfa hay	40	3.0	13
Municipal sludge (digested)	31	4.5	7
Soil microorganisms			
Bacterial	50	10	5
Fungi	50	5	10
Soil organic matter	46-56	2-5	9-23

Consider the mineralization rates of compost types in south Florida (Table 2). It shows the N released after a 6-month field incubation period. Note that the lowest C:N ratio released the highest amount of N to the soil solution.

Table 2. Mineralization rates of compost (South Florida)

Compost Type	C%	N%	C/N Ratio	N released, %
Sewage sludge	28.3	4.9	6	22%
Municipal solid waste	28.9	1.9	15	7
Yard waste	11.0	0.3	37	2

Another example comes from a California compost study (published in HortScience 31: 961-964 in 1996) using composted green yard and landscape waste (Table 3). 'A' through 'C' in the table below represent a sample obtained from the site over a 4- to 6-week interval.

Table 3. Characteristics of compost source and stage of decomposition.

Source	C/N Ratio	CEC	Ec	Tomato seed germination	N released
South California					
A	11.1	29.9	11.4	86%	-8.4%
B	10.8	32.2	14.7	20%	-8.4%
C	11.8	30.7	12.8	55%	-13.6
North California					
A	10.2	44.3	5.8	96%	-6.3%
B	9.2	38.7	7.7	69%	-5.6%
C	8.9	42.2	8.3	84%	+5.1%

Notes:
Look at the amount of N released. **Why the negative value when the C/N ratio is low?**

Answer: It reflects the 'age' of compost. This was immature compost, resulting in absorption of N because of microbe buildup.

Particularly note the 'germination' percentages. The high Ec (electric conductivity or salinity) values reflect differences in water quality between the two areas, evapotranspiration rates and the make up of ash. There was a high negative correlation of Ec with tomato seed germination. Be sure you know the Ec value of any added compost. The unit of Ec measurement is dS/m or mmhos/cm, the older term which is still used by many laboratories. There is a specific soil test procedure to measure the Ec, so it is recommended to have it conducted with the usual pH, P and K during a soil test.

Considerations when adding organic amendments to the soil:

- They are highly variable in composition and quality.
- No standards for labeling exist.
- Make sure you analyze each load or shipment.
- They are more expensive to transport, store, purchase and apply.
- Some may contain sewage sludge (possible high heavy metals).

Nitrogen must be mineralized to the soluble form for plants. There is no accurate formula or lab test to predict the rate of mineralization. The availability of N declines as manure ages. Wetting, drying, rainfall and microbiological activity affect the amount of inorganic N that is lost through leaching and volatilization [ammonia (NH_3) - high heat greater than 120 -130^oF] and the remaining N that is stabilized in humus-like compounds.

Nitrogen is more available poultry manure than in horse, cow or sheep because it contains uric acid. Also, other animals have more roughage in the diet - N less readily decomposed due to presence of lignin and cellulose.

Table 4. Comparison of decomposition rate of young grass and straw.

	Start			After 180 days		
	%N	C/N	lignin	%N lost	C/N	humus
Young grass	3.7	12	low	55	9	high
Straw	0.5	85	high	0	48	low

According to the United States Composting Council (USCC), compost chemical analysis should include:

- **pH** (look for 6.0 to 7.5).
- **Ec** (look for 5.0 or less). Plant tolerance to salinity varies widely. Usually, approximately 1 dS/m is best. Snap bean yields are reduced 19 percent for each 1 dS/m increase; strawberries show a 33 percent reduction for each 1 dS/m above the threshold. However, beets and zucchini can be grown at 4 - 4.7 dS/m.
- **C:N ratio** (recommend an initial of 30:1). Mature compost should be between 10:1 to 15:1.
- **Bulk density** (solids/moisture content; expressed as lbs/yd^3). It is useful in determining rate of application
- **Heavy metals** – Zn, Cd, Cu, Ni, Pb, Hg, Mo, As, Cr, Co.
- **Overall nutrient profile** – essential plant nutrients (i.e., N, P, K, etc.).

Salinity

Salt buildup in high tunnel soils has become a more prevalent issue where the cover is left on year around. A way to reduce the problem is to leave the sides rolled up so winter snows and late winter rains can leach the salt out of the root zone.

<u>Symptoms of high soil salinity:</u>

- Root dieback, root tips burn off.
- Plant stunting - all parts: leaves, stems, roots, fruits.
- Leaf burn - edges, lower leaves.
- Wilting - high osmotic pressure prevents root uptake of water. Worse in hot, dry weather. Salinity sensitivity varies among plant genera.

High salinity (salt buildup) in the root zone may be due to:

- Poor placement of fertilizer - starter at planting, poor mixing in pots, etc.
- Fertilizer salts mainly due to K and nitrate (but could be Na, Ca, Mg, Cl, SO4) .
- Evapotranspiration greater than irrigation.
- Too much fertilizer applied - excess of plants needs.
- High water table - evaporation from soil surface causes groundwater to move up, carrying salts into the upper level.

When reducing high salt levels:

- Monitor soil salt levels with the Ec test during routine soil sampling.
- Place tunnel on well-drained site, add tile line.
- Be careful with nutrient applications, do not over fertilize.
- Limit the use of organic sources containing animal manures.
- Keep sides rolled up in winter.
- Leach salt downward in the soil profile via irrigation.
  generally, for 1 foot of soil:
  - 6 inches of water will leach out 1/2 of the salt
  - 12 inches of water will leach out 4/5ths or 80 percent of the salt
- Constant watering with trickle irrigation techniques moves salt to the outer edge of the wetting zone and helps reduce the symptoms.

Table 5. Salinity sensitive of specific crops.[1]

Ec (dS/m) associated with a 10% yield reduction	
Vegetables	
Muskmelons	3.6
Tomatoes	3.5
Sweet Corn	2.5
Peppers	2.2
Lettuce	2.1
Snap Beans	1.5
High tolerance (10-12 Ec) = spinach, asparagus, kale, beet	

[1]Adapted from E.V. Maas, Crop Tolerance, *California Agriculture* (October 1984).

Figure 4. Effect of high root zone soluble salts on plant growth.

Research at Penn State found that soils in high tunnels had salt levels ranging from 0.37 (no salts) to 9.38 regardless of whether inorganic or organic fertilizer sources had been used.

high salts = plant death

Table 6. Example of wood ash addition to cultivated soil.

Wood Ash Addition to Soil					
Treatment	**pH**	**Soluble salts, Ec**	**P**	**K**	**Cl**
None, soil	6.9	-	-	-	-
½" ash	8.8	0.2	5	100	20
1" ash	9.6	0.4	10	> 250	200
1 ½" ash	9.8	0.4	15	> 250	200

- ash mixed thoroughly with top 6 inches of soil
- no heavy leaching

Note: The greatest effect was on soil K and pH - both increased dramatically.

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High Tunnel Selection

By Eldon Everhart
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Objectives:
You will:

- Learn about several issues that need to be considered prior to constructing a high tunnel.
- Become familiar with different sizes and types of high tunnels that are being used in horticulture crop production.

Size of the Operation

The most important issues to consider before constructing a high tunnel are the location, available budget and potential crops. When considering where to locate your first high tunnel, it is wise to plan for expansion. Also consider the market area and the number of plants you expect to grow. Include space for roadways, parking lots and snow removal as well as for grading, packaging, storage and sales.

Other considerations include orientation, airflow, shading, windbreaks, drainage, soil quality, weeds and other pests. Make sure to consider how irrigation and power will be delivered to the tunnel, including during winter months if winter production is intended.

High tunnels are relatively labor-intensive structures and require frequent access. In most situations, there is an advantage to locating high tunnels close to the house where the owner or manager lives. Truck and tractor access is essential for moving product and supplies in and out. Proximity to the washing area, restrooms, packing shed and processing and distribution areas will simplify the operation.

Also consider the need for basic equipment and supplies during the initial planning stages. Basic equipment and supplies include the design and installation of a watering system, incorporation of injectors for fertilizer applications, delivery vehicles, soil sterilization equipment, pesticide spraying equipment and storage area, soil mixing equipment, chemical and tool storage, office supplies and equipment, rest rooms for employees and customers, and lunch room and break area for employees.

Shade can greatly reduce the effectiveness of a high tunnel since it limits light. Locating high tunnels north of any substantial obstacle, such as a tree or building, is undesirable. If you cannot avoid building a tunnel near an obstacle, ensure that the space between the tunnel and the obstacle is at least two times the height of the obstacle. For example, if there is a 25-foot tree on your property, the high tunnel needs to be located at least 50 feet from that tree. If building multiple high tunnels oriented east-west, the spacing among the tunnels needs to be twice the height of the tunnels. If the tunnels are oriented north-south, the spacing can be 4 feet among them.

Know the cropping or vegetative history of the proposed site. Avoid locating a tunnel where there are soil-borne diseases or significant annual or perennial weed problems, or correct those problems before constructing the tunnel.

Movable tunnels are typically sited in a production field, so a high tunnel's impact on the growth and management of the crops around the tunnel must be considered. There must be sufficient room around a mobile high tunnel for the equipment and/or people that will be needed to move it.

Manufactured

High tunnels can be constructed from a variety of materials. Make sure that the structure and covering best suit your budget and the intended purpose of the high tunnel. There are differences in construction and price. When possible, choose structures that are made of materials with the lowest environmental impact.

Figure 1. Prefabricated high tunnels are available from several manufacturers. They are delivered disassembled in a box. Read and follow the directions carefully.

Metal pipe is the strongest and most durable framing material for rib construction. Metal pipe ranges in quality, from electrical conduit (the weakest) to Schedule 80 water pipe (the strongest). Schedule 40 (3/4-inch galvanized water pipe) is commonly used, but it is 20 percent weaker than Schedule 80 pipe. Although metal ribs are very strong, they are also heavy and more difficult to maneuver. Metal pipe is also used to construct the end walls.

Homemade

Homemade high tunnel supporting structures or framework are usually less expensive and often less permanent than commercially manufactured structures. The structure should be fabricated so that a standard-sized plastic cover may fit the structure. Materials that can be used to build the structure include new or recycled lumber, rebar, metal pipe, plastic pipe or a combination of these and other building materials.

The supporting structures for small high tunnels have been made with polyvinylchloride (PVC) pipe. As a building material, PVC is cheap, durable, lightweight, easy to maneuver, and easy to assemble. Although PVC tubing has been used for home-made high tunnel frames, Dr. Henry Taber, Extension Vegetable Crop specialist, does not recommend the use of PVC because it can destroys the plastic covering within a year. He also warns that it is a relatively weak material for rib construction and high tunnels made from plastic hoops are highly vulnerable to wind and snow load collapse. PVC expands and contracts with temperature changes and deteriorates over time. There are also human health concerns related to PVC manufacture and disposal (Altshyler, et al. 2007).

Wood is not typically used for rib construction but is often a component of end walls, hip boards and baseboards. To comply with organic certification standards, lumber treated with a prohibited substance cannot be used in any new installation or replacement structures if it comes in contact with the soil, crop or livestock.

Due to its impact on human and animal health, chromated copper arsenate (CCA) pressure-treated wood is no longer legal for residential and general consumer uses in the United States. Alternatives to lumber treated with prohibited materials such as CCA include untreated wood, wood treated with a compliant substance, steel, materials made from recycled plastics, cement board panels, concrete blocks, stone, brick and concrete. Growers who are certified organic can use naturally rot-resistant woods such as cedar, cypress, black locust, Osage orange and white oak.

Borate materials are commercially available arsenic-free wood treatments that have been used for years to protect wood against insect pests and decay. Boric acid is a synthetic substance allowed for use on certified organic enterprises for “structural pest control, [not in] direct contact with organic food or crops” [Compliance and Enforcement Directives of the National Organic Standards section 205.601(e)(2)].

A description of the construction of a high tunnel designed by researchers at Pennsylvania State University is presented in a report in HortTechnology (Lamont, et al. 2002). The report is available online at: plasticulture.cas.psu.edu/Design_construction.pdf.

Another plan for a homemade high tunnel, developed by Amanda Ferguson at the University of Kentucky, is available on the Internet at: uky.edu/Ag/NewCrops/hightunnel.pdf.

Size

When determining what size of high tunnel is appropriate, consider if the tunnel will provide enough room to plant, monitor, maintain and harvest the crop from inside the structure. In some cases, the tunnel will need to be large enough to accommodate small tractors for cultivation and spraying.

Tunnel dimensions vary widely among manufacturers and construction plans. A typical tunnel is 15 to 30 feet wide and 60 to 96 feet long. Wide tunnels have the advantage of being easier to manage. In most cases, tunnel width should not exceed 30 feet.

Tunnels exceeding 96 feet in length pose some potential problems. Ventilation is limited, and long tunnels in use during the winter may collapse due to heavy snow loads. The height of the peak may range from 7 to 15 feet. Wide tunnels provide more planting area are often taller than narrower tunnels. The latter, however, usually have more stable temperatures at the level of the plants. Vents installed either in the roof or on the end walls below the peaks will allow hot air to escape and draw cool air into the structure. The taller the tunnel, the better the air flow moving into the tunnel through the side vents and out the vents in the roof or end walls. Even when the sides are rolled up, the temperatures inside low tunnels without vents can damage plants on calm, sunny summer days.

The two main types of tunnels are: single bay and multi bay. Single-bay high tunnels are free standing, or not connected to another high tunnel. Multi-bay high tunnels are two or more tunnels connected along the sides. They may also be referred to as gutter connected.

Shape

The shape of a tunnel affects its performance. It will have an effect on lighting (and shading), energy gain, growing space and ventilation. Single-bay high tunnels come in two primary shapes: Quonset (hoop) and Gothic arch (Figure 2).

The Quonset shape is relatively short and squat with a rounded roof and sloped sides, while the Gothic, like a cathedral, has a high pointed peak and straight sidewalls. Unheated Quonset structures can also serve as cold frames for overwintering nursery stock. Gothic-shaped tunnels have several advantages compared to Quonset models. In some circumstances, these advantages can justify their generally higher cost.

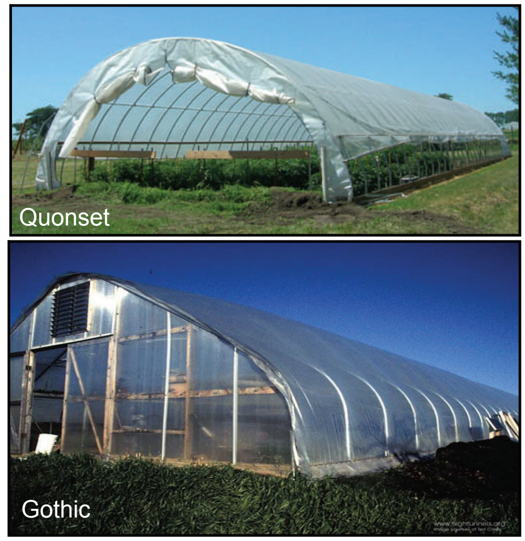

Figure 2. High tunnel shapes.
(Photo credit: Ted Carey, Kansas State Horticulture Research and Extension Center.)

A Gothic-shaped structure readily sheds snow because of the steep pitch of its roof and has a 15 percent greater load-carrying capacity than a Quonset high tunnel. Quonsets, especially those with PVC bows, need to be swept free of snow to prevent collapse. When snow threatens, some growers set up 2 x 4 inch boards as temporary props under the ridge pole, purlins or bows of their Quonset-shaped high tunnels. PVC tunnel owners are wise to remove their plastic for the duration of the snowy season.

Multi-bay high tunnels, manufactured first by Haygrove and now by other companies, are usually a series of interconnected Quonset-shaped tunnels. Most multi-bay tunnels cover large areas and, per bay, are relatively inexpensive.

It is important to match your structure's design load to local snow and wind conditions. Some high-tunnel suppliers have design specifications for their structures for different areas of the country.

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

The greater height of Gothic tunnels allows for better ventilation through higher gable-end vents. Because of their angle, Gothic arch roofs tend to shed water that condenses on the interior, rather than drip on the plants below.

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

For a list of high-tunnel structure suppliers, go to Appendix F, Structure Suppliers, on page 84 or to hightunnels.org/resources for sources of structures and other production equipment and supplies.

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High Tunnel Construction

By Dr. Eldon Everhart
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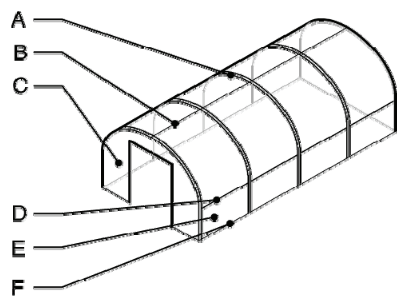
Objectives:
You will:

- Become familiar with the major components of a high tunnel and their function.
- Learn about the high tunnel construction process.
- Learn how temperature, humidity and wind can be managed in a high tunnel.

Major components

Most tunnel framing consists of steel pipe. Although PVC tubing has been used for home-made high tunnel frames, it is not recommended for a long-term structure. Framing pieces are bent into bows and form the ribs of the high tunnel. The following diagram provides basic terminology associated with high tunnel framework.[1]

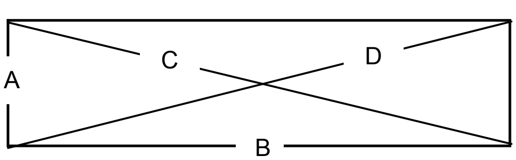
A. Rib, Hoop, Arch, Bow
B. Purlin, Ridgepole
C. End Wall
D. Hip Board
E. Side Wall
F. Baseboard



Construction tips

- Always follow the manufacturer's construction manual or the do-it-yourself design plans for high tunnels.
- The closer the tunnel is to plumb, level, and square during the construction, the easier its sides will roll up.
- Tunnel construction is far easier on level ground.
- After soil preparation and site grading, mark the corners of the specified dimensions of the high tunnel. Use the formula shown below to make sure the corners are square. Take one final measurement to insure that "C" equals "D."

Figure 1. In Iowa, space posts every four feet, as opposed to the recommended six feet.



$A^2 + B^2 = C^2$

Depending on the model of high tunnel under construction, metal posts are driven into the ground along the sides of the tunnel at set intervals (Figure 1).

[1]www.hightunnels.org/ForEducators/Planning/Materials.htm

Because of the strong winds in Iowa, it is advisable to space posts every four feet as opposed to the recommended six feet. Decreasing rib spacing also increases the amount of load that the structure can carry. The posts need to be set at approximately 2 feet in depth. Using a level twine at a measured point from the top of all the posts will help to make the high tunnel level. This will make the rest of the construction and plastic installation easier.

Figure 2. Post set in concrete.

For additional anchorage, a post hole may be augured at every other post location. Some growers chose to set these posts in concrete. In high wind areas, if you don't set every post in concrete, experts recommend that you set at least the corner posts and every other post in concrete (Taber and Kubik 2008) (Figure 2).

Figure 3. The metal bows are attached to the side posts.

The metal bows or ribs are then attached to the ground posts and fastened in place with bolts (Figure 3). Purlins and the top ridgepole are installed after the ribs are in place (Figure 4). This task is easier if several people are available to hold the ribs upright (Figure 5).

Figure 4. Purlins and the ridgepole connect the ribs together for support and strength.

Most pre-fabricated or manufactured high tunnels have parts that need to be fitted together and held in place with TEK screws. TEK screws are self-drilling and self-tapping without the need for a pilot hole. When assembling these parts, it is best to do it on a large, relatively flat surface, such as a parking lot. The pipes also need to be assembled with care. Some might look alike but have slight differences in degree or angle of the bend, making their assembly even more critical.

Hip boards are secured to the posts or ribs about three to five feet above the ground to help stabilize the structure and are used to anchor the plastic in place. If the hip boards are installed level, the roll-up sides work more efficiently.

Figure 5. Several hands are needed to hold the metal bows or ribs while they are being installed.

Baseboards are attached on the bottom of the high tunnel at the soil line. They are typically constructed of rot-resistant wood, such as cedar (Figure 6).

Figure 6. Baseboard.

Before installing the plastic, cover or wrap all sharp edges, including bolts, to prevent tearing (Figure 7).

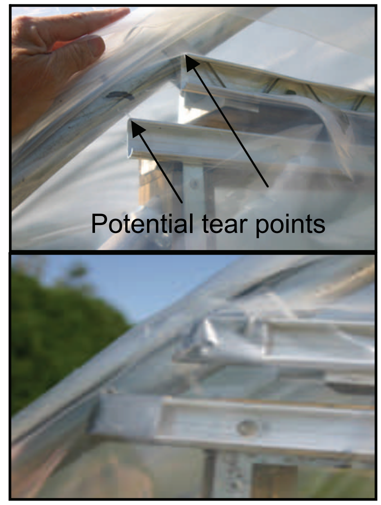
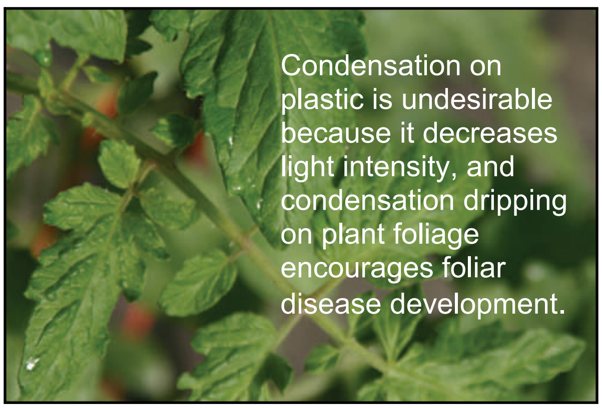


Figure 7. Duct tape or single-sided adhesive foam can be used to prevent plastic covering from tearing at stress points.

Coverings

Greenhouse-grade polyethylene, a plastic film, is the most common material used for covering high tunnels. Polyethylene is sold by thickness in mils (1 mil = 1/1,000th of an inch) and rated for longevity in years. Typical specifications for a high tunnel covering would be a single layer of greenhouse-grade 6-mil polyethylene rated for 5 years. Traditional permanent greenhouses usually have two layers of polyethylene, separated by air blown between the layers, to reduce heat loss during cold season production.

Some polyethylene glazing films contain additives designed to enhance durability and strength. Additives increase the cost and some may reduce light transmission. Ultraviolet (UV) stabilizing additives block UV light to slow degradation and hardening of plastic. Construction-grade plastic does not contain a UV-inhibitor and will only last one growing season.



Anti-fog surfactants make water condensing on poly film sheets run down to the sides of the structure, rather than beading and dropping on the foliage of plants below. Infrared (IR) radiation-blocking additives reduce the amount of IR radiation that passes through the plastic. Polyethylene alone is a poor barrier to IR radiation. IR-reflecting poly can block IR heat loss by half, which can translate to a 15-25 percent reduction in the total heat loss at night. These films can also be used to reduce heat build-up during warm weather. However, a single layer of IR-absorbing poly decreases photosynthetically active radiation (PAR) transmission to 82 percent. PAR is the light used by plants for photosynthesis and growth. In addition, these materials will slow tunnel warming (Runkle 2008).

Figure 8. Several people located along each side make it easier to unfold and secure the plastic.

Covering the frame

To apply the plastic cover over the high tunnel frame, choose a time of day that is relatively calm with little or no wind (e.g., early morning). It is best to choose a warm day and let the plastic warm up so it will be easier to handle and stretch more than if it is cold. The more hands available to hold the plastic makes the job easier (Figure 8).

An efficient way to get the plastic over the ridgepole is to tie tennis balls along one edge of the covering every 8 to 10 feet with a rope long enough to stretch over the ridge-pole and down the other side. Toss the loose end of the rope over the top, and at the same time, slowly pull all of the ropes evenly over the frame. Unroll the plastic as it is pulled with ropes over the top of the tunnel. Allow at least 8 to 12 inches of overhang on the end so that the plastic may be adjusted later if necessary and to facilitate rain runoff. Fasten the plastic from the top down (Figures 9 and 10). After one end is secured, pull the plastic cover tight and fasten the opposite end. Do not pull the cover too tight; it may cut during fastening. To help prevent the sides from flapping and chafing in the wind, straps made of batten webbing are often fastened to hook eyes in the hip board and tossed diagonally over the high tunnel and fastened on the opposite side.

Figure 9. Fasten the plastic to the side or hip boards, mounted approximately 5 feet above the soil line on each side of the tunnel.

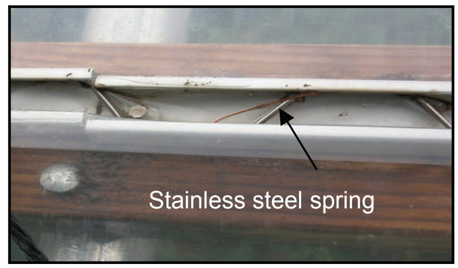


Figure 10. Stainless steel springs, tucked in an aluminum channel on the hip boards, offer continuous force along the surface of the plastic, are relatively easy to install and do not tear the plastic.

End walls

Figure 11. Endwall.

The end walls of high tunnels are often made of plastic (Figure 11). Zippered ends or a large door must be constructed in the end walls to permit ventilation in the summer as well as entrance and exit of equipment. End walls with zipper openings can be purchased as an optional item from some manufacturers. Doors can be hinged on the sides or on the top. Smaller doors can also be installed for easy access of workers. The materials to construct tunnels end walls are typically not included with manufactured high tunnels.

Twin-wall rigid plastic or corrugated structural sheeting can be used for end walls. These walls transmit approximately 80 percent of solar radiation, have a higher insulation value than plastic film, and are light weight. Twin wall sheets are shatterproof and can be cut with a saw (Blomgren, et al undated).

Roll up versus roll down sides

The side walls on high tunnels can either roll up to open or roll down to open. Those that roll down to open may have several slight advantages. When partly rolled down, they provide protection from wind blowing directly on small plants growing in the outside row next to the side wall. This may prevent some abrasion of plant leaves and stems caused by windblown grit. Lesions caused by such abrasion may provide entry wounds for some plant diseases.

Manual versus automated side walls

The side walls of a high tunnel can either be opened by hand using a screw lever (Figure 12) or automated with an electric motor (Figure 13). Motorized sidewalls are activated by a thermostat inside the high tunnel and the vents open and close automatically within preset temperature ranges. The advantage is that someone does not need to be present for the system to work. However, if the system fails to work, heat could build up inside the tunnel and possible plant or crop loss could result. If an automated system is present, then a buzzer or phone alarm hooked up to a thermostat inside the high tunnel might prevent a catastrophe. Also, a person operating a manual system can be more proactive and react to pending outdoor weather conditions even before the changes occur.

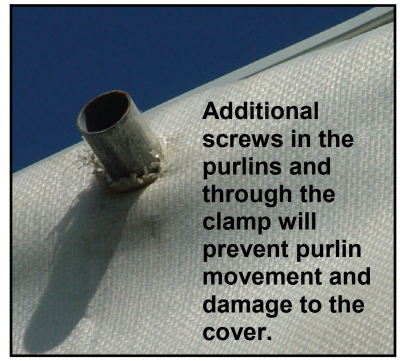


Figure 12. Manual side walls.

Figure 13. Automated side walls.

Replacing the cover

Removing the plastic is completed in reverse order of plastic cover application. Replacing a cover depends on the age and wear of the plastic but should be done every three years for tunnels in year round use because light transmission levels drop as the plastic ages. The plastic may be usable for longer periods on tunnels that are used only to extend the end of the season. Most wear and tear of plastic is caused by fasteners, reducing the life of the plastic. When not in use, multi-bay tunnel covers are rolled and rest in the alleys where the bays connect to keep them off of the ground. To protect them from sun exposure and degradation, tunnel covers should be covered with black plastic when rolled.

Regular maintenance

Plastic covers should be inspected regularly for wear and tear. Rips should be immediately repaired with clear tape. If the plastic remains on the tunnel for the winter, periodic removal of snow load may be needed to avoid structural weakening or collapse. This is best done with a non-pointed object, such as a long-handled floor broom head or squeegee, before ice or a stiff crust forms.

Climate variability

The locations of plants in a high tunnel and the plant canopy have an effect on temperature variations. Some producers may expect high tunnels to extend the production season in the fall by protecting the crop from early frosts. However, the frost protection provided by the high tunnels is minimal.

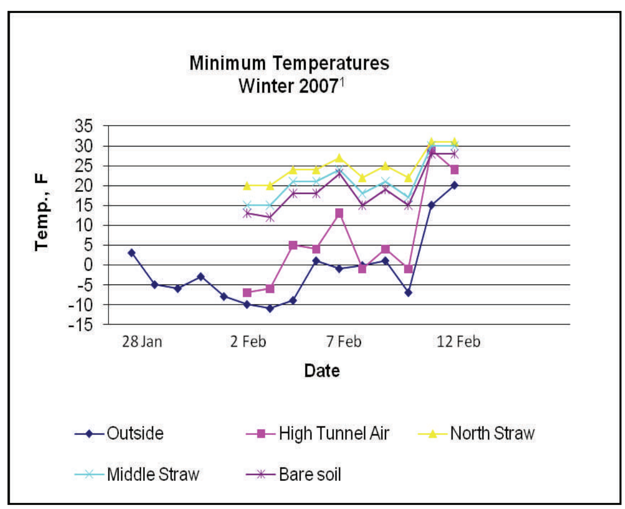


Figure 14. [1]Minimal winter temperatures recorded outside and inside the high tunnel and under straw mulch in two locations in the tunnel at the Horticulture Research Farm, Ames, Iowa.

High tunnels are most often used in Iowa to facilitate early production rather than late-season extension beyond the fall frost period.

Figure 15. Row covers placed over hoops along the row provide some additional frost protection.

Temperature

High tunnels should be designed and managed as passively vented and solar heated structures. However, supplemental heat (propane space heaters, wood stoves, etc.) can be used to temporarily protect the crops from lethal freezes. Thermal blankets, row covers and water bags may also protect crops from lethal freezes (Figure 15). Most severe freeze events are limited but can cause significant damage (Figure 16).

Figure 16. Frost damage to pepper transplant.

High temperature can be as damaging to crops as low temperatures. Excessively high temperatures can cause flowers to fall off tomatoes and peppers as well as reduce pollination, resulting in a lower percentage of marketable fruit.

Temperatures inside high tunnels can often reach or exceed levels considered damaging to even the most heat-tolerant crops. However, there are usually few indications of heat stress on either the plants or fruit inside a properly managed high tunnel. Stress related to dehydration may be avoided through careful attention to availability of soil moisture. Daytime humidity levels inside high tunnels are usually relatively high. This may slow water use, thereby reducing the risk of heat related moisture stress.

Shade cloth, and vents in the roof, end walls and side walls are the most effective ways to moderate temperature inside a high tunnel. Shade cloth is made from knitted polyethylene strands or woven polyester and is water permeable. Shade cloth is used to reduce light intensity, temperature, and plant exposure to wind. Shade cloth is often used in combination with plastic covering, but in some applications in warm climates or during the summer, it can be used as the sole covering for a high tunnel. Black, white and various shades of green and brown are available. Shade cloth is rated by the percent of light blocked, varying from 20 to 90 percent. Seasonal and crop species requirements dictate which percent shade cloth should be used. A 50 percent white or black shade cloth is commonly used.

Humidity

Careful ventilation will help to keep relative humidity at lower levels and to keep the foliage dry, preventing disease outbreaks. Proper use of drip irrigation will also keep the humidity low. High tunnel sides should be opened each morning to dry the leaves that have collected condensate during the night.

Wind

Trees, shrubs and fabricated material like wood lath can be used as a barrier to moderate and/or redirect wind. Windbreaks could consist of woody shrubs designed to be harvested for fruit or flowers.

Air pressure builds up on the side toward the wind (windward side) and air moves over the top and around the ends of the barrier. The height, density, orientation and length of a windbreak affect the area protected by it.

The interaction between the height and density of the windbreak determines the degree of wind speed reduction and the downwind area protected. The height of the windbreak is the most important factor in determining the amount of area protected downwind. Wind speed reductions are measured on the side toward the wind (windward side) for a distance of two to five times the height of the windbreak. Wind speed reductions are measured on the side away from the wind (leeward side) for a distance up to 30 times the height of the windbreak.

The orientation of windbreaks should be at right angles to prevailing winds that occur during the most critical periods of the production season. Examples of critical periods are cold winter winds carrying snow or strong prevailing winds that may damage plants near the sides of a high tunnel during the spring or summer when ventilation is required (Figure 17). Windbreaks on the north side of a high tunnel should be about 100 feet away, keeping snow drifts away from the structure. The length of a windbreak should be ten times longer than it is high. Gaps in the length of windbreaks decrease their effectiveness by creating funnels or lanes that concentrate wind.

Figure 17. Strong spring winds can damage young plants growing near the sides of the high tunnels. Note the differences in plant size from the outside toward the inside of this high tunnel.

Ventilation

Temperatures inside a high tunnel can be regulated by opening and closing tunnel sides, end doors and peak vents (Figure 18). Sides may be opened up fully or partially, depending on outside temperatures. During the summer, tunnel sides can remain open day and night. In the spring and late fall, the goal is to retain as much heat as possible inside the high tunnel during the night. When outdoor temperatures cool off at night, the tunnel sides should be closed in the late afternoon or even sooner.

Figure 18. This rooftop vent allows hot air to escape when additional ventilation is needed on extremely hot and humid days.

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Mulches and Drip Irrigation for High Tunnels

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Objectives:
You will:

- Be able to evaluate high tunnel cropping situations where either organic or plastic mulches would be optimum.
- Become familiar with the six types of plastic films and the advantages of each.
- Learn how to schedule irrigation and how much irrigation water to apply.

Plasticulture system

Plastic mulches, also called polyethylene, and drip, or trickle, irrigation are the main components of the plasticulture system that has revolutionized vegetable production, particularly warm-season crops. Other components of the system for outdoor production are windbreaks, raised beds, transplants and row covers.

Figure 1. Plastic mulch improves efficiency and yields in vegetable production.

The main **advantages** of such a system include:

- Season extension (both spring and fall).
- Higher yields per unit area (2 to 3 times higher).
- Cleaner and higher quality produce.
- More efficient use of water - uses 50 percent less with trickle versus overhead irrigation.
- Reduced leaching of fertilizer (nitrogen).
- Reduced soil erosion.
- Fewer weed problems.
- Reduced soil compaction and elimination of root pruning.
- Potential decrease in incidence of disease.
- Better management of certain insect pests.
- Opportunity to double crop with maximum efficiency.

Of course, there are some **disadvantages**:

- Plastic disposal problems.
- Cost of material, application and disposal.

Mulches

The increase in soil temperature is probably the most important factor for the success of polyethylene mulches. A higher soil temperature, particularly at night or the minimum, is more favorable for continued root growth. Research in central Iowa has shown that early muskmelon yield with clear plastic has been double that of black plastic and four times the production from bare soil. The results with tomatoes have been less dramatic; enhanced early growth is dependent on the coolness of the spring weather.

Organic mulches, on the other hand, tend to keep soil temperatures cool, delaying onset of flowering and reducing early yield (Table 1). Organic materials should not be applied to spring crops in the high tunnel. Also, some growers have attempted to reduce the cost by 'painting' the soil with black latex paint. Early work using petroleum (asphalt) mulch in California in the late 1960s and early 1980s in Iowa showed the minimum soil temperature was actually reduced (Table 2). This was the result of the asphalt in firm contact with the soil acting as a black body, radiating heat back into the atmosphere at night.

Table 1. Effect of plastic mulch on early tomato yield, cv. Jetstar, at Sutherland, Iowa, 1980. Transplants set May 14. First harvest was from black plastic on July 27 and yield data taken to August 3. Soil type was a silty clay loam, moderately well drained.

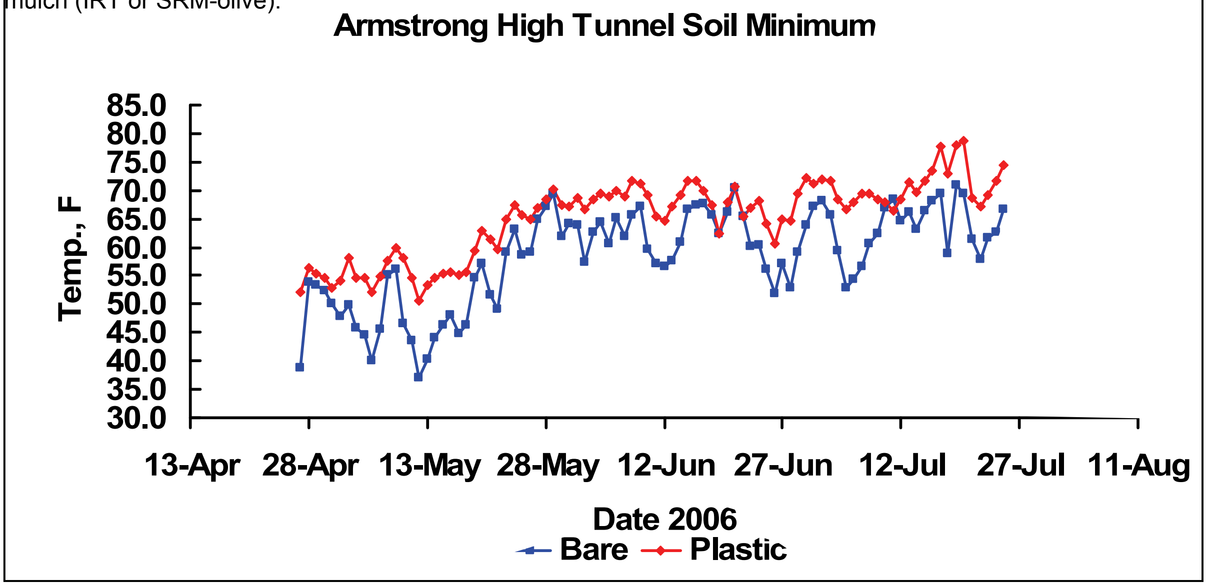
Mulch Treatment	Yield, cwt/acre
Bare soil	74
Straw	52
Black plastic	104

Table 2. Effect of mulch treatment on muskmelon, cv. Gold Star, early yield at Ames, Iowa, 1985. Transplants set May 10 and early yield from August 5 to 13.

Treatment	Yield, crates/acre	Fruit size, lbs ea.
Clear plastic	343	4.5
Black plastic	242	5.4
Asphalt	27	4.3

Most plastic mulches will trap heat and increase slightly the minimum soil temperature which will promote root growth (Figure 2). However, it is the high soil temperature that occurs at midday that gives the greatest effect on plant growth (Figure 3).

Figure 2. Minimum soil temperature, usually 7 to 8 am, as influenced by wavelength selective polyethylene mulch (IRT or SRM-olive).



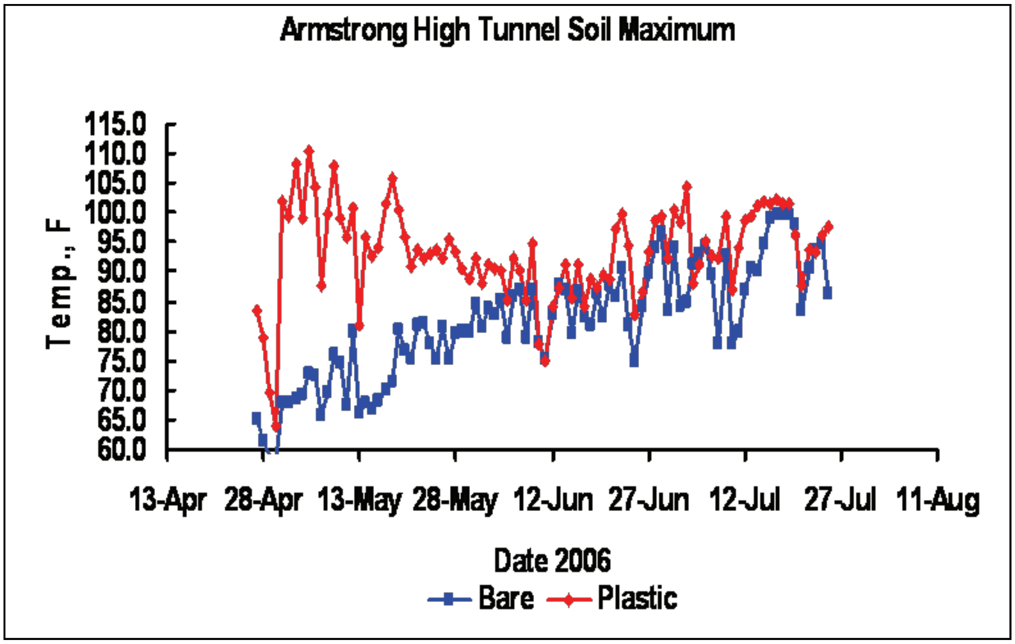


Figure 3. Effect of wavelength selective polyethylene mulch (ITR or SMR-olive) on the maximum soil temperature, usually 3 p.m.

The dramatic effect of increasing spring soil temperature on tomato growth and development and resulting yield is shown in Figure 4. The use of black polyethylene mulch on raised beds is not recommended when transplanting crops in mid-July to early September due to considerable heat buildup under the plastic and on the surface of the film. Instead, a high opaque white or metalized silver mulch promoting cooler soil and surface temperatures is recommend during these times.

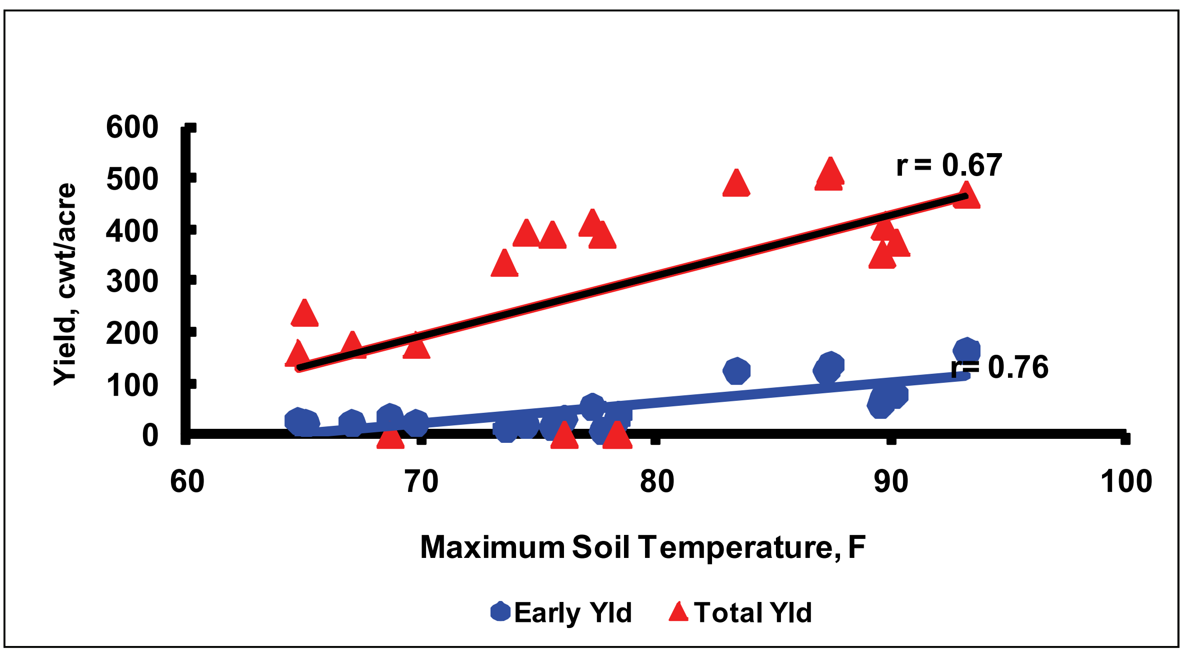


Figure 4. Polyethylene mulch effect on tomato yield as a result of 4-inch soil temperature, from 1997 to 2001 studies, Iowa.

Vegetable crops most suitable for high tunnels and most responsive to plastic mulches are tomatoes, peppers, eggplants, cucumbers and summer squash.

The polyethylene mulches are produced as either linear low or high density (more strength), 0.5 to 1.25 mil thickness. The thicker the film, the longer it can be left in place, even double cropped. Also, the thicker film is easier to remove by hand but costs more. While energy costs have risen dramatically in the last 3 years, plastic film manufacturers have saved money on the production of mulch film by reducing the thickness of the film. Film thickness has gradually decreased from 1.5 mil to 0.5 to 0.7 mil in the last 3 years. The thinner mulch film does reduce the amount of resin required to make the product, and in most cases, also reduces the cost of the roll compared to the 1.5-mil material. The one disadvantage of the thin plastic film is the retrieval for growers after the crop has been harvested. Thin films 0.7 mil or less do not retrieve from the field very easily and thus are difficult to recycle.

Biodegradable films are still in the experimental stage but look very promising. Two types are currently being developed, either based on fermentation chemistry or a different type of polyethylene chemistry.

Common plastic mulch sizes, depending on the region of the country, are 48 to 60 inch wide in rolls of 2,000 to 4,000 feet. Three feet wide black plastic is also available. Most are manufactured as embossed in a diamond-shaped pattern for strength and to add ‘stretch’ across the bed. Many colors are available, with reported yield and/or quality enhancement: black, clear, white, silver, red, brown, green, yellow and blue. The mulch modifies the microclimate by increasing soil temperature and reflectivity while decreasing soil water and nutrient loss.

Black

- Opaque, black body absorber that radiates energy.
- Absorbs most ultraviolet, visible and infrared wavelengths of incoming radiation.
- Re-radiates energy in form of thermal radiation or long-wavelength infrared back into atmosphere at night.
- Becomes an energy sink during the day, causing possible plant stem damage.
- Much of the energy absorbed by black plastic can be transferred to the soil by conduction if a good contact exists between the mulch and soil surface.
- Compared to bare soil, daytime temperature approximately 5 degrees F higher at the 2-inch depth and 3 degrees F higher at the 4-inch depth.

Clear

- Absorbs very little solar radiation.
- Transmits 85 to 95 percent to the soil, depending on thickness and degree of opacity of the polyethylene.
- Condensed water droplets on the under surface are transparent to incoming shortwave radiation, but opaque to outgoing long-wave infrared radiation, so much of the heat lost to night sky by bare soil is retained by clear plastic mulch.
- Daytime high temperatures are 8 to 14 degrees F higher at the 2-inch depth and 6 to 9 degrees at the 4-inch depth.
- Used for vine crops that are very responsive to soil temperature.
- Must use a herbicide to control weeds. Soil fumigants or solarization are used in Arizona, California and Texas to kill weed seeds.

White and Silver

- Reflects radiation, with soil temperature resulting in a slight decrease of -0.7 degrees F at the 4-inch depth.
- Southern states (South Carolina, Georgia, Florida) establish a crop when soil temperature is high (late summer).
- Silver reflects incoming radiation, which causes disorientation of insect flight, particularly aphids.

Red, Brown, Green (wave-length selective or photo-selective)

- Selectively transmits (brown, green) or reflects (red) radiation.
- Transmits: selectively reflective mulch (SRM)-brown, transmits radiation in region of electromagnetic spectrum but not the photosynthetic region (PAR) – the blue-green part of the spectrum (430 to 480 nm). They transmit solar infrared radiation, resulting in soil temperature response between black and clear plastic while preventing most weed growth (Figure 5).
- They are also called infrared transmitting (IRT) mulches.
- Reflects: SRM-red, radiation principally in the red and far-red region.

Figure 5. Tomatoes growing on red plastic mulch.

[red (R) = 620 to 640 nm and far-red (FR) = 730 nm]

- The change in the R:FR ratio is known to affect flower development, fruit set and carbohydrate accumulation in tomato fruits, resulting in increased maturation. The mulch is also translucent, resulting in a soil-warming effect.
- Cost is about 1.5 times that of black plastic.

Yellow, Blue

- Attracts insects such as green peach aphid, striped and spotted cucumber beetle, leafhoppers.
- Can be used as a trap crop.
- Blue has been shown to increase muskmelon, cucumber and summer squash yield by 20 to 30 percent over 3 years in trials at the Penn State Center for Plasticulture (Figure 6).

Figure 6. Cucumbers growing on blue plastic mulch.

Disposal

Current use of plastic film for the production of horticultural crops in North America is estimated at 600,000 acres per year. Unfortunately, after the growing season is over, the plastic film has to be discarded after being retrieved from the field. Some plastic film mulch can be recycled, but because much of the plastic film used in vegetable crop production is dirty, wet and contains possible pesticide residues after retrieval, much of the film is discarded by placement (not visible to the general public) in private landfills.

Biodegradable Film

Biodegradable plastic mulches offer the potential of tilling the film into the soil after crop harvest and saving at least $100 in plastic mulch pickup and disposal. Penn State University research in 2005 and 2006 found the crop yield of cantaloupes, honey dews and bell peppers grown on black biodegradable mulch film was as prolific as the nondegradable mulch films. However, if the plastic degrades before the crop matures, weed competition may significantly reduce either yield or quality of the harvested crop.

Biodegradable mulch also costs about 50 percent more than current nondegradable plastic mulch and is based on a different type of chemistry. Efforts continue with paper mulches without commercial success. Wax-coated products are the latest development but still tear easily on application, and the breakdown process cannot be regulated. The cost is also prohibitive. Research is focused on increasing the strength of the paper so that it can be used with common mulch-laying equipment.

Mulch application

The inherent differences in regional micro-climates across Iowa suggest that growers be conservative in setting out early plantings in high tunnels. Remember, high tunnels do not give much protection against freezing temperatures. Even if plants survive colder temperatures, certain physiological disorders can result from transplant stress that can significantly impact vegetable yield and quality. Two examples are "buttoning" in broccoli and cauliflower and "catfacing" in tomato (Figure 7). Both of these physiological disorders result from temperature stress following transplanting. Therefore, when selecting a transplant date, it is important to bear in mind that survival does not necessarily equal success.

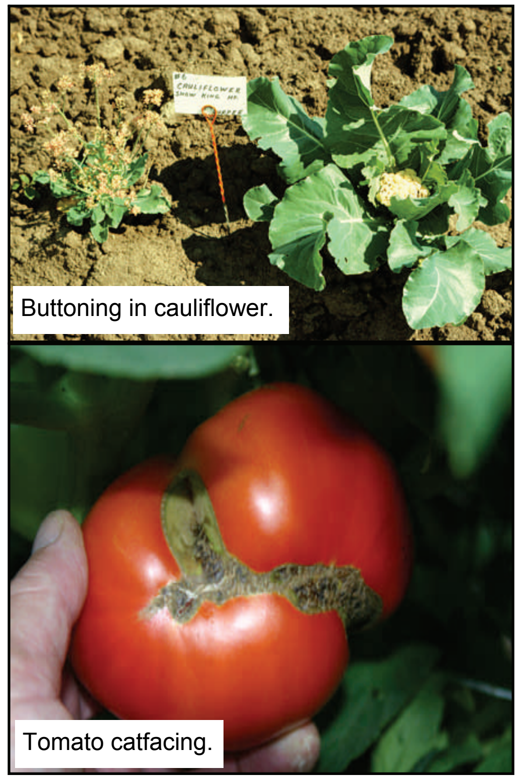


Figure 7. Vegetable disorders as the result of cold temperatures.

Because of the width and height of high tunnels, a smaller, modified plastic mulch layer was designed for use in high tunnels (Figure 8).These mulch layers will make a 3- to 4-inch high bed, 18 inches wide from 36-inch wide plastic. The beds are spaced on 44-inch centers; thus a 17-foot wide high tunnel can accommodate four beds, while a 21-foot wide high tunnel can accommodate five beds. The drip tape is generally placed 2 inches deep, and depending on the crop being grown, either placed in the center or one side of the bed. For tomatoes, the tape is placed on one side of the bed, and a single row of tomato plants are established in the middle of the bed. For pepper, the tape is placed in the middle of the bed, and two rows of pepper plants are established on either side of the drip irrigation tape approximately 12 inches apart.

Figure 8. A "mini" mulch layer (right) is designed for high tunnel use.

Sources of Colored Plastic Mulch

Clarke Ag Plastics
P.O. Box 238, Greenwood, VA 22943
Phone: 540-456-4578. Fax: 540-456-6403.
http://www.cstone.net/~agmulch/about.html
Low density, highly reflective (metalized) silver/black or clear – smooth or embossed.

Integrated Packaging Americas
3115 35th Avenue, Suite 201, Greeley, CO 80634.
Phone: 970-339-5103
e-mail: kseese@ipstretch.com.
Black, clear and silver.

Ken-Bar, Inc.
25 Walkers Brook Drive, Reading, MA 01867-0704
Phone: 800-336-8882
http://www.ken-bar.com/
All films are high-density, embossed polyethylene. Black, silver/black, white/black, SRM-olive (IRT-Green), SRM red and black paper mulch.

Mulch Film. Com – John Weiswasser
Phone: 610-909-7594
http://www.mulchfilm.com/
All colors are offered as embossed or taffeta films. Black, reflective white, IRT green, IRT brown, co-extruded white/black, blue, red, clear, co-extruded 20 black strip on Super Brite aluminum

Pliant Corporation
1515 Woodfield Rd. Suite 600, Schaumburg, IL 60173
Phone: 866-878-6188
http://www.pliantcorp.com/
All films are embossed. Black, black/white. white, clear, blue, thermic olive, and olive green.

Reflectek Foils Inc.
1075 Brush Hill Lane, Lake Zurich, IL 60047
Phone: 888-439-6121
Website: http://www.repelgro.com
Metalized UV reflective – silver/black, silver/white, black and white. Both embossed and smooth film offered.

High tunnel and plasticulture related websites:

plasticulture.cas.psu.edu, The Penn State Center for Plasticulture.
plasticulture.org, American Society for Plasticulture.

Trickle Irrigation

Trickle, or drip, irrigation (sometimes called 'micro-irrigation' in the trade literature) is almost used exclusively in high tunnels. Overhead irrigation is not conducive to the mulch system and defeats the purpose of disease control. Some key points of the system are:

- Wets only a portion of the root zone.
- Usually associated with plastic mulch.
- High management, compared with overhead.
- Higher quality and possibly higher yields.
- Installation costs lower than overhead on acreages smaller than 5 acres.

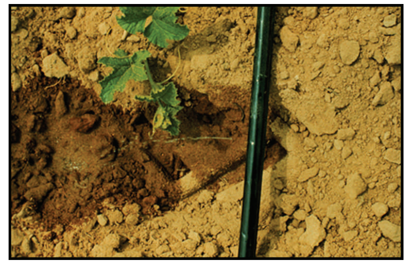


Figure 9. A young melon transplant being drip irrigated.

Advantages:

- Low flow rate.
- Smaller pump (less energy).
- Less capital expenditures for a small acreage.
- Space between rows not wetted.
- Automation possible.
- Apply during windy conditions.
- Decreased damage may be realized.
- Fertilizer can be applied, if needed.

Disadvantages:

- Increased management skill needed.
- Higher daily maintenance.
- Clean water essential; emitters may clog.
- Frost protection not provided.
- Moisture distribution limited on sandy soils.
- Lateral line damage, such as from rodents, insects and labor.

Three factors affects soil water loss: crop species, weather and soil type.

The rate of water loss from a **crop species** depends on:

- Rooting depth.
- Planting density.
- Shading of ground.
- Mulching, if any.

The **weather** parameters that affect water loss are:

- Temperature.
- Light intensity.
- Wind speed.
- Relative humidity.

The **soil type** has a direct effect by its:

- Texture - sandy, loam or clay.
- Water-holding capacity of the particular type.
- Infiltration rate.

Table 3. Rooting depth of various crops. The bolded crop names means plastic mulch generally is used with this crop and the rooting depth is shallow.

Shallow, 6-12 inches	Moderate, 18-24 inches	Deep, more than 36 inches
Broccoli Greens Onion Snap beans **Pepper**	Cabbage **Cucumber** **Muskmelon** **Eggplant** Potato **Tomato**	Asparagus Lima Bean **Watermelon** (seeded)

The amount of water a soil type can hold is referred to as 'soil water-holding capacity' (WHC), and values are given in inches per foot (Table 4). Also, the amount is at field capacity (after saturated rainfall and gravitational force has removed excess water). Thus, it is important to know the soil type when calculating the amount of water to apply.

The trickle system wets only a portion of the root zone, so you should only allow 25 to 30 percent depletion of available soil water before turning on the irrigation system.

The available water for plant growth and development is a product of the soil type and the effective rooting depth.

For example, a mature tomato crop grown on plastic mulch in a loam soil would have an available water amount of 3.75 inches.

Table 4. Water-holding capacity for various soil types.

Soil Texture	Inches/Foot
Sands	0.5 – 1.0
Sandy loam	1.0 – 1.5
Loams	2.0 – 2.5
Silt loams	2.5
Clay loams	2.0 – 2.5

Loam = 2.5 inch per foot (Table 4) **× effective rooting depth of 1.5 feet** (Table 3) **= 3.75 inches of water**

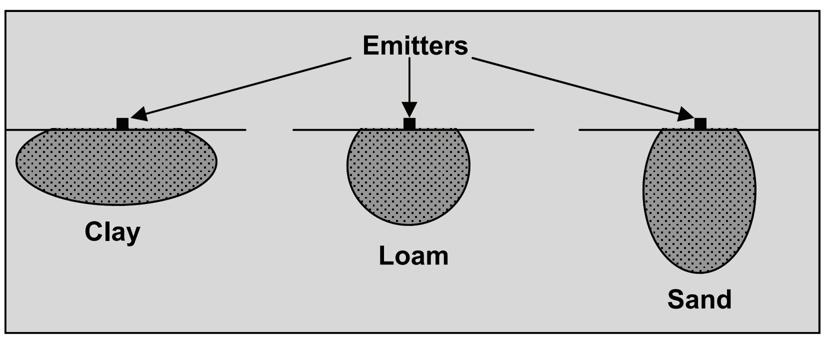


Figure 10. Soil wetting pattern from water application through a trickle system.

How fast is the crop using water? Some indicators would be:

- Plant appearance = poor (signs of wilting).
- Soil appearance = better (see Midwest Vegetable Production Guide, FG-600 for a chart at: public.iastate.edu/~taber/Extension/index.htm).
- Soil moisture meters = best. Two excellent choices are tensiometers and watermarks.

To properly schedule irrigations and to determine how much water to apply, tensiometers should be used for each type of crop (Figure 11).

The reading on the tensiometer gauge shows the relative wetness of the soil. The higher the reading, the drier the soil. The numbers from 0 to 100 are called centibars (cbars). One hundred cbars equals 1 bar or 1 atmosphere. A tensiometer can operate effectively within a range of 0 to 80 cbars. A zero reading indicates a saturated soil in which plant roots will suffer from lack of oxygen. Zero to 5 is too wet for most crops. The range from 10 to 25 cbars represents ideal water and aeration conditions. As readings advance higher than 25, water deficiency may occur for sensitive plants having shallow root systems, such as plants growing on coarse-textured soils.

For detailed information on the use and care of tensiometers, see Appendix D, *Tensiometer Tips for Vegetables*, on page 75.

Tensiometers should be set at two depths:

- Shallow = 1/3 to 1/2 of the crop effective rooting depth.
- Deep = bottom of the root zone (Figure 12).

Figure 11. 6-inch and 12-inch tensiometers with vacuum gauges and ceramic cups.

Scheduling Irrigation

To determine when to water, first determine how much root zone water has been lost. Apply water when there is no more than a 25 to 30 percent depletion in the limited wetted zone; remember a high tunnel is more like a desert than a typical Iowa field (Table 5).

To determine how many gallons of water you need to replace, consider the ‘bathtub’ approach. In other words, what is the crop-wetted volume of soil in terms of gallons and at 25 percent depletion? Determine how many gallons you need to replace it. Most values are given per acre, so a final calculation will be to convert from acres to square feet of tunnel area.

Figure 12. Two tensiometers set at two different depths give a good estimate of soil moisture at effective rooting and just below the root zone.

Example
Using the principles and tables discussed above, let's consider an example using a pepper crop growing in a high tunnel in central Iowa soils.

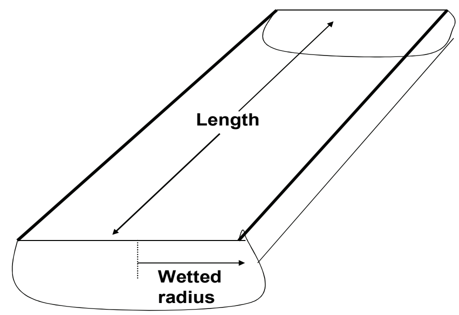
Soil type = Clarion loam – a loam holds 2.4 inches available water per foot per acre (refer to Table 4).

Rooting depth = 1.0 feet for pepper (refer to Table 3).

Bed or row spacing = 4.5 feet between rows (peppers have been planted in twin rows, 18 inches apart, on 4-foot wide plastic with in-row spacing at 15 inches. There can be other variations of the planting arrangement. In a 30 × 96 foot tunnel, this allows six rows wide by approximately 90 feet long).

Wetted radius of bed = 16 inches (or 32 inches diameter or equivalent to 2.67 feet). The wetted radius will vary according to soil type.

Crop wetted volume = Use the given formula that 1 acre-inch of water = 27,000 gallons.



Crop Wetted Volume

Thus, we have six rows by 90 feet = 540 linear feet of bed. With 2.67 feet of wetted diameter × 540 linear feet = 1,442 square feet or 0.033 acres (1,442/43,560 square feet in acre) under plastic or the trickle system.

Also, our rooting depth is 1.0 feet × 2.4 inches of water per foot = 2.4 inches of water per foot per acre at full crop wetted volume (field capacity). But, we only have 0.033 acres so 2.4 × 0.033 = 0.794 inches × 27,000 gallons per inch = 2,145 gallons available to the crop at field capacity. If we allow a 25 percent depletion before turning on the pump, then the tensiometer should read 25 cbar (Table 5) and we would have lost 536 gallons of water (2,145 × 0.25 = 536).

Table 5. Useful set points for tensiometers.

Soil Texture	Field Capacity[1]	25 Percent Depletion[2]
Sandy loam	5 - 10	10 - 15
Loams	10 - 15	20 - 30
Silt loams	15 - 20	25 - 35
Clay loams	25 - 40	40 - 50

[1]Field capacity values indicate no irrigation required.
[2]25 percent depletion of the available water (AWC) in the crop effective root zone.

Finally, turn on the pump. When the shallow tensiometer reads 25 cbar, apply about 540 gals (using a flow valve or calculating run time based on system delivery). To calculate pump runtime, you need to know the trickle emitter delivery rate. For vegetables, a typical system might deliver 0.53 gallons per hour per emitter. Thus, for our system, the 540 linear feet of row = 540 emitters, 0.53 gallons per hour per emitter = 286 gallons per hour for the system. If we need to replace 536 gallons (from above), then 536/286 = 1.87 or 2 hours to run the pump.

It is advisable to record tensiometer readings throughout the season.

As one would expect, growers differ in their management practices to maintain tensiometer readings at the 20 to 30 cbar range (Figures 13 and 14). It is a good idea, initially anyway, to have two tensiometer locations within a crop and average the two readings to avoid possible errors in placement.

Summary: What you need to know to operate a trickle irrigation system

1. Soil water volume available to the crop.

- Soil type to determine AWC at field capacity.
- Wetting radius (or diameter) of trickle application and length of lateral run.
- Linear feet of crop system to calculate acres under plastic.
- Effective rooting depth of the crop.
- Calculate available gallons at field capacity for the crop acreage.

2. How fast is the crop losing water.

- Remember, allow only 25 to 30 percent depletion of AWC.
- Tensiometer trigger point for soil type (from charts).

3. How long to run the system.

- Emitter output in gallons per hour per 100 linear feet.
- (From 1 above) how many 100-foot units for the crop acreage?
- Calculate system delivery in gallons per hour per crop acreage.
- (From 2 above) divide gallons needed by the delivery rate to see how long to run the pump.

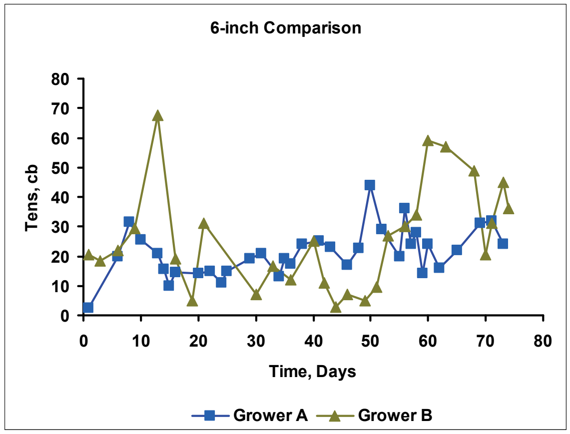


Figure 13. Two growers' ability to maintain the 6-inch tensiometer reading between 20 to 25 cbars for a high tunnel tomato crop.

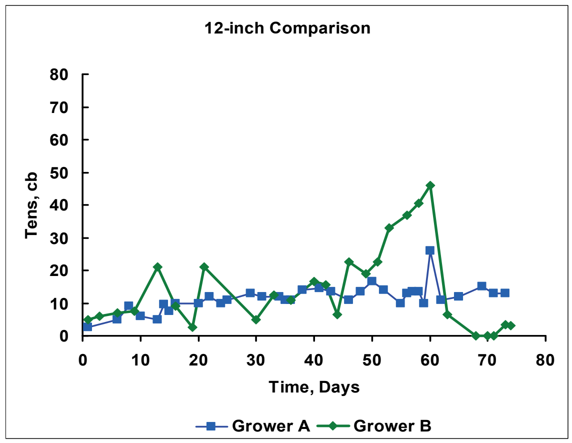


Figure 14. Two growers' ability to manage the deep tensiometer, 12 inch, at 10 cbar reading. A 10-cbar reading indicates aeration porosity and indicates ample water supply without excessive leaching or wide fluctuation in water quantity.

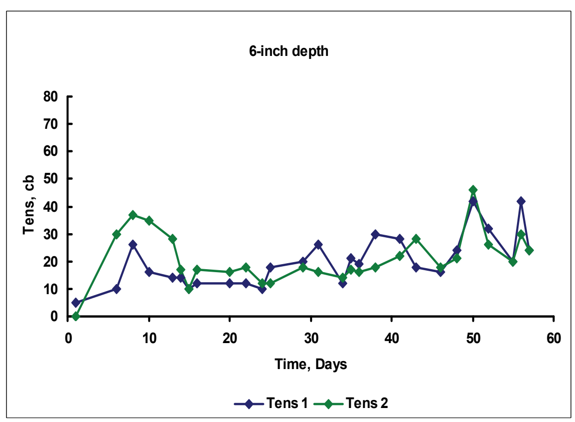


Figure 15. Comparison between two tensiometers set at a 6-inch depth at different crop locations within the tunnel.

Planting Bed Arrangement and Plant Spacing

By Linda Naeve
Extension Program Specialist, Value Added Agriculture, Iowa State University

Objectives:
You will:

- Learn how planting bed arrangement can affect yields and income.
- Understand how plants can be arranged along the row for maximum efficiency and productivity.

Figure 1. Row or bed configuration in a high tunnel is determined by the crops grown, management and maintenance needs.

Efficient and productive space utilization is as important in a high tunnel as it is in a greenhouse. The greater percentage of space utilized in crop production will result in increased profit per square foot. However, some area needs to be open for ready access to all portions of the tunnel. A good tunnel arrangement optimizes crop production and accessibility. Sometimes growing space has to be sacrificed for efficient management.

The style of the high tunnel may also determine the bed arrangement and placement. Gothic-style high tunnels generally have taller sides than the arched Quonset-style, enabling producers to get equipment closer to the sides of the tunnel.

Longitudinal Bed Arrangement

Planting parallel to the long axis of the tunnel is the most typical arrangement and is practical for laying plastic and drip lines (Figure 2). It allows for efficient installation and management of trellises and row covers. Long rows are a desirable arrangement for single-crop production in a high tunnel (Figure 3). Space utilization varies considerably, depending on the row width and the row spacing.

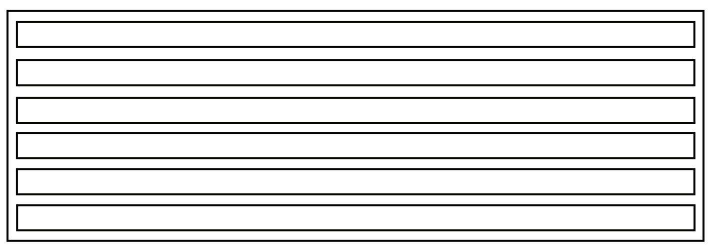


Figure 2. A series of beds or rows arranged along the long axis of the tunnel is a simple system, especially if only one or a few crops are grown. This shows a longitudinal arrangement in a 30 × 96 foot high tunnel.

Figure 3. Longitudinal bed arrangement is efficient for single-crop bays.

However, plants grown along the sides of a high tunnel may exhibit an “edge effect,” displaying poorer growth due to cooler temperatures in the spring, wet soils from inadequate drainage or wind damage.

Lateral Bed Arrangement

Orienting beds laterally across the width of a high tunnel is another option. It is a good arrangement when several different crops are grown or different planting times are scheduled (Figure 4). This bed layout actually provides slightly more growing space than beds arranged longitudinally in the high tunnel.

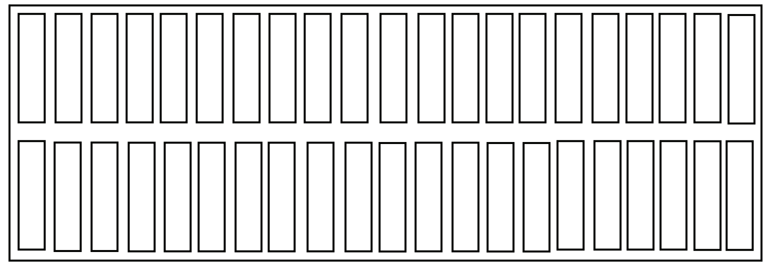


Figure 4 . The central aisle in a lateral bed arrangement makes it easier to harvest and haul product out of the high tunnel.

If you are interested in winter production, configuring lateral beds north-south in a high tunnel with an east-west orientation will result in less shading. This bed arrangement enables you to cover the entire tunnel with just two large pieces of row cover, one to the left of the center aisle and one to the right (Blomgren et al. 2007).

Plant Spacing

The ability to grow the plants vertically by trellising and the dry (no rain) environment make higher plant populations feasible within a high tunnel. Plant population can be increased to nearly double the plant density of field-grown crops. Crops requiring more growing room are typically planted in single rows within the bed. Many crops can be planted in double rows (twin rows) within one bed or strip of plastic. The two rows are typically spaced 12 to 18 inches apart. Staggering the plants so that two plants in double rows are not side-by-side allows for closer planting with adequate room for growth (Table 1 on next page).

Reference

Blomgren, T., T. Frisch and S. Moore. Undated. High tunnels: using low-cost technology to increase yields, improve quality, and extend the season. University of Vermont Center for Sustainable Agriculture. (Available as download or for purchase as video and manual at: uvm.edu/sustainableagriculture/hightunnels.html) (verified June 2009).

Table 1. Suggested spacing of horticultural crops when transplanted or seeded in high tunnels.[1]

Crop	Within-row spacing (inches)	No. of rows/bed[2]
Vegetables		
Melons	24	Single (optional trellis)
Cucumber	12-14	Single (optional trellis)
Summer squash	36	Single
Eggplant	18-24	Double (staggered planting)
Pepper	16	Double (staggered planting)
Tomato (staked)	18-24	Single
Lettuce	4-12	Double
Spinach	4	Double
Swiss chard	8	Double
Kale	8	Double
Kohlrabi	6-8	Double
Onion	6-8	Double
Leek	4-6	Double
Potato	6-10	Double (staggered planting)
Cabbage	12	Double (staggered planting)
Broccoli	12-16	Double (staggered planting)
Cauliflower	12-16	Double (staggered planting)
Okra	12-16	Double (staggered planting)
Pole beans	8	Single (trellis)
Bush beans	3	Double (bare ground)
Small Fruits		
Raspberry	30	Single (bare ground, 6 feet between rows)
Blackberry	40	Single (bare ground, 6 feet between rows)
Cut flowers		
Small-sized (12-20” tall)	8	Double (14” between rows)
Large-sized (>20’ tall)	12	Double (14” between rows)

[1]Adapted from: Lamont, William J., Michael Orzolek, E. Jay Lolcomb, Kathy Demchak, Eric Burkhart, Lisa White and Brice Dye. 2003. Production Systems for Horticultural Crops Grown in the Penn State High Tunnel. HortTechnology 13(2). pp. 358-362.

[2]Double row = two rows per bed or strip of plastic,12 to 18 inches apart; the recommended bed spacing is 4.5 feet from center to center, assuming 4-foot wide plastic mulch is used for most crops. Single row = one row per bed or strip of plastic.

Integrated Pest Management in High Tunnels

By Dr. Donald Lewis
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Objectives:
You will know the

- Components of integrated pest management.
- Importance of integrated pest management to growers and the environment.
- Variety of control tactics available to manage insects, diseases and other pests.

High tunnels create a unique environment that may lead to different disease problems and insect pests than the grower may encounter in the field. Also, the earliness of crops grown in a high tunnel may help avoid some pests that normally become established later in the season. However the generalities of integrated pest management (IPM) still apply.

IPM (integrated pest management) is a common-sense, holistic approach to dealing with pests. It can be described as the use of knowledge about the crop, the cropping system and the pests to systematically use all appropriate control tactics, thus avoiding unacceptable loss and minimizing adverse side effects. In other words, IPM requires growers to use their knowledge of plants and pests and the environment in a sensible way to reduce the number of pests before they do unacceptable damage.

IPM uses a combination of pest control tactics, including pesticides as needed, and after other options have been considered. The basic components of IPM are:

- Prevention.
- Monitoring.
- Control techniques.

Prevention

Pest prevention requires using knowledge of past and potential pests to avoid future problems. Proper selection and care of plants will result in healthier plants that have fewer pest and disease problems or plants that are more tolerant of minor maladies.

Prevention activities include:

- Choosing resistant and adapted species and cultivars when available.
- Planting according to best management practices (right seeding or transplant depth, proper planting time, plant spacing, etc.).
- Planting disease- and pest-free transplants and seeds. Inspecting carefully before purchase and planting and discarding any infested, discolored or stunted plants.
- Using sanitation. Picking ripe produce frequently and cleanly and removing damaged and fallen produce from the high tunnel. Removing dead plant debris as soon as the produce is harvested and controlling or removing weeds before they produce seed.
- Irrigating and using mulch to minimize plant stress.
- Fertilizing according to need as determined by soil test and incorporating organic matter to improve plant health.

Monitoring

Monitoring, also called inspection, detection and scouting, is finding pests and diseases early before pests reach damaging levels or while controls will be most effective. Monitoring can rely on trapping devices, such as yellow sticky card for thrips, aphids and whiteflies, or on visual inspection of plants to look for hornworms, cutworms and foliage diseases and disorders. Look at all plant parts for presence of insects, mites and diseases (leaf undersides, stems, buds, flowers). Certain diseases are best managed by monitoring the weather conditions rather than looking for signs and symptoms of the disease. Monitoring provides information to aid in your pest control decision-making process.

Figure 1. Inspect plants for insect and disease problems twice a week.

Inspect the plants in the high tunnel at least twice a week (Figure 1). Count pests in specific locations in the high tunnel and on specific plant parts, depending on the pest and the crop. Record number found and stage of insect growth (egg, immature, adult). Include crop observations (height, leaf color, bud development, symptoms and signs, etc.).

Control Techniques

Cultural, mechanical, biological and chemical management tactics can be used alone or in combination to meet the goal of reducing or preventing pest injury. Cultural controls are horticultural practices that limit pest populations or reduce the amount of damage that pests might cause.

Cultural controls, described earlier as prevention measures, include:

- Maintaining plant health.
- Making proper plant selections.
- Choosing resistant varieties.
- Using crop rotation.
- Following other practices that maintain healthy, vigorous plants.

Mechanical, or physical, controls separate the pest from the crop by means of a device or an action. Effective devices might include fences to keep out rabbits out or screens and row covers to exclude insects from plants. Actions might consist of handpicking pests directly from plants. Pests such as slugs, potato beetles, hornworms and cutworms can be removed and destroyed from a few plants when pest numbers are low, such as when one or a few tomato hornworm caterpillars are in the high tunnel. Other actions might include forceful water sprays to dislodge aphids or pruning to remove diseased or infested plant material. Hoes, cultivators, rototillers, other tools and hand pulling may be used to kill weeds.

Not all mechanical controls are effective. Ultrasonic and electromagnetic electronic devices neither successfully repel insects nor attract them so they can be killed. The same can be said for bug zappers; they may actually be harmful by killing more beneficial insect predators than pests. Insect traps, such as yellow sticky cards, are ineffective as controls; their main utility is in detecting the presence of insects so other control measures may be taken if necessary.

Biological control, also called biocontrol, uses living organisms to suppress or limit pest populations. Biological controls do not eliminate pests but may help keep pest populations down; consequently, a low level of injury should be expected. Depending on the tolerance level, biological controls may or may not be an acceptable option for pest control.

The organisms that attack pests are called natural enemies; they can be categorized as: (1) predators, (2) parasitoids and (3) pathogens. The two main ways to use biological control are: (1) augmentation and (2) conservation. Augmentation, the release of specific beneficial organisms within an area for control of an existing pest population, is moderately successful in enclosed environments such as greenhouses, but it is uncertain in the outdoors. For example, buying lady beetles for release in the high tunnel is generally not effective; most fly away immediately while others leave if pests (food) are not present in sufficient numbers.

Conservation of natural enemies preserves those already present. To preserve natural enemies, furnish them with food, shelter and a safe environment. Pests are food for natural enemies; therefore, a few pests must remain if natural enemies are to survive. This probably means there will be at least a low injury level.

To help keep the environment safe for natural enemies, reduce the use of broad-spectrum pesticides, which injure or kill a wide variety of organisms, including beneficial ones.

Pathogens are microorganisms (bacteria, fungi, viruses and nematodes) that weaken and kill pests by creating a disease or infection. A few disease pathogens including *Bacillus thuringiensis* (Bt) and entomopahtogenic nematodes are available for application to crops.

Pesticides are chemicals (naturally occurring or synthetic) that adversely affect unwanted insects, weeds or plant pathogens; affect plant growth; or repel pests from an area. IPM includes the judicious use of pesticides as a chemical management tool. Pesticides can be carefully used in combination with other tactics or if other tactics do not give the desired level of control. Careful use requires thoughtfully chosen and properly timed applications of the least toxic alternatives. Give special consideration to "soft" or "reduced risk" compounds such as insecticidal soap, ultrafine horticulture oil, neem compounds and other plant-based insecticides for treating pest hot spots.

Environmental consequences especially need to be considered when using pesticides. Special attention should be taken, for example, to avoid pesticide use when plant pollinators or natural enemies are present.

High Tunnel Insect Control[1]

Major insect and mite pests of high tunnel crops include aphids, thrips, whiteflies, spider mites, tomato hornworms and other caterpillars, and cucumber beetles.

[1]Adapted from Leopold Center "High Tunnel Pest Scouting Model" at http://www.leopold.iastate.edu/research/marketing_files/pest.pdf and University of Missouri Extension "High Tunnel Melon and Watermelon Production" at http://extension.missouri.edu/publications/DisplayPub.aspx?P=M173.

Hornworms and other caterpillars of tomato and peppers

Tobacco and tomato hornworm damage usually occurs from midsummer to fall. The large caterpillars eat large irregular holes in the leaves and may quickly defoliate plants. Hornworms are often difficult to see because their color provides effective camouflage. Hornworms tend to feed on the interior of the plant during the day and are more easily spotted when they move to the outside of the plant at dawn and dusk (Figure 2).

Figure 2. Tomato hornworm.

Fruitworm caterpillars vary in color from pale yellow to red to green to brown with pale stripes running lengthwise. After the egg hatches, the larva feeds for a short period of time on the foliage before attacking the fruit. They prefer to feed on green fruit and usually do not enter ripe fruit. Damage consists of deep watery cavities frequently in the stem end of the fruit. During its development, one larva may injure several fruit.

Inspect tomato plants, checking for frass, damage and caterpillars. Look for fruitworm larvae on fruit and on the leaves near green fruit and outer edges of the plant. The threshold in the high tunnel is one caterpillar. Hornworms can be handpicked. Insecticide sprays, especially Bt, will be more effective against small caterpillars.

Whiteflies

Whiteflies are tiny (1/16 inch long) insects that resemble tiny white moths that disperse from the plants when disturbed (Figure 3). They are most common on tomatoes and melons in late season. The damage is done by nymphs (immature stage) as they suck the sap from the plant leaves. Whiteflies can also spread viral diseases. Plants should be inspected for signs of off-color or stunted plants. Scout plants regularly by checking undersides of new leaves for adults and underside of older leaves for nymphs. Yellow sticky cards will monitor adults. Spray with insecticide such as insecticidal soap when there is 0.5 whitefly per sticky card early in the season and two per card per day as the crop reaches maturity.

Figure 3. Whiteflies on pepper.

Aphids

Winged aphids migrate into the high tunnel from wild hosts and establish colonies on the plants. Aphids are soft-bodied, pear-shaped small insects that may be found on stems but are usually on the underside of the leaf (Figure 4). Aphids suck sap from the plant, causing the leaves to curl under and become deformed ("cupping") and weaken the plant. Aphids are also vectors of certain plant viruses.

Figure 4. Aphids on pepper.

Scout plants closest to tunnel openings for infestations, focusing on undersides of leaves and growing tips. A wide range of control options exist, depending on crop and management philosophy. Systemic insecticides can be used at transplanting on some crops. Contact insecticide or naturally existing natural enemies may keep numbers tolerably low.

Spider mites

Spider mites are very tiny (about 0.5 mm long) and live on the undersides of plant leaves where they puncture plant cells to feed on the sap. Severe spider mite damage will result in speckled "bronzing" discoloration of the leaves, reduced growth of the plant and possible early defoliation and plant death (Figure 5). Two-spotted spider mites thrive in hot, dry weather and are more likely from mid season through fall. Inspect leaf undersides for eggs webs, cast skins and all stages of the spider mite (Figure 6). Control weeds a practice clean mowing around the tunnel to help prevent movement in from outdoors. Begin treatment when symptoms appear, using insecticidal soap or other miticide. Miticides do not kill eggs so repeat application should be considered.

Figure 5. Spider mite damage to raspberries grown in a high tunnel.

Thrips

Thrips are small (1/16 inch long) and elongated insects found in flowers or on the undersides of leaves, depending on the crop. Damage to the plants is caused by adult and nymph thrips scraping the surface of the leaves with their mouthparts and feeding on the exuding sap. The damaged plants will have small, silver streaks on the leaves, and the plant looks as though it has been sandblasted. Early detection of thrips is important. Regularly and frequently inspect plant blossoms and leaf undersides. Sticky traps (blue or yellow sticky cards) can detect winged adult thrips. Systemic, targeted insecticides applied at transplanting will be effective in controlling thrips for about 35 days on certain crops. Spray contact insecticides, including insecticidal soap, for control.

Figure 6. Closeup of spider mites and their webbing.
(Photo credit: David Cappaert, Michigan State Univ.)

Cucumber Beetles

The same striped and spotted cucumber beetles that attack field-grown cucurbits and transmit bacterial wilt can damage high tunnel melons. Overwintered adults feeding on transplant leaves and stems can kill small plants (Figure 7). Plants that survive may be infected with bacterial wilt pathogens and succumb to the disease in mid season. Striped cucumber beetle adults frequently feed on the fruit surface, reducing aesthetic appeal and creating openings for sap beetles and disease organisms.

Figure 7. Striped cucumber beetles.
(Photo credit: Clemson University - USDA)

Beetles can be excluded from transplants by using row covers in the high tunnel. Systemic insecticides applied at transplanting will provide up to 35 days of control, which is long enough to reduce bacterial wilt infection. Further control through the growing season can be accomplished by applying foliar insecticides. Avoid using insecticides that may be toxic to pollinating insects. There are no effective biological control techniques for cucumber beetle.

High Tunnel Plant Disease Control[2]

High tunnels can reduce disease impact by elevating soil temperatures slightly but enough to prevent common cool weather damping-off and root rots, and by keeping foliage dry, thus preventing the establishment of most (but not all) foliar diseases.

Unfortunately, powdery mildew can germinate in the absence of free water and can be an even more serious problem in high tunnels than in the field-grown crop.

Disease management in the high tunnel should include the following considerations:

- Use plastic mulch combined with trickle irrigation to keep foliage dry and reduce splash of soil-borne pathogens.
- Maintain humidity to remove excess moisture that provides conditions conducive to certain diseases. Use ventilation by raising and lowering the plastic sides of the high tunnel and follow plant-spacing guidelines to allow good air flow within the tunnel and around plants.
- Use disease-resistant varieties when possible and always start with disease-free seed and transplant.
- Provide optimal growing conditions through proper irrigation, fertilization, staking, pruning and other cultural practices to increase plant health and vigor.
- Practice sanitation to remove and destroy infected plants as they are found. Pick produce frequently, cleanly and completely. Remove all over-ripe and damaged produce from the tunnel to reduce inoculums. Remove all plant residues at the end of the season.
- Practice crop rotation. Rotate annual crops among structures or among zones within the structure.

Powdery Mildew

Powdery mildew is a major problem for all crops; the environmental conditions in a high tunnel favor its development. As the name suggests, powdery mildew produces white, powdery colonies on leaves, petioles and stems of infected plants, usually appearing on the lower leaves and gradually spreading through the canopy. Plants become weakened from leaf loss, and fruit size can be significantly reduced. Choose resistant cultivars when possible and inspect plants regularly, starting at fruit set. Many effective fungicides are labeled for powdery mildew control, including several synthetic fungicides and organic products such as mineral oils (JMS Stylet Oil) and potassium bicarbonate (Armicarb, MilStop and Kaligreen). Alternate synthetic fungicides to prevent the development of resistance.

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[2]Adapted from "Disease Management in High Tunnels" in "Minnesota High Tunnel Production Manual for Commercial Growers".
Available online at: http://www.extension.umn.edu/distribution/horticulture/components/M1218-9.pdf

Business Planning and Marketing for High Tunnels

By Ray Hansen
Extension Specialist, Value Added Agriculture

Objectives:
You will:
- identify the key components of a complete business plan.
- You will develop justifications for why a high tunnel makes sound business sense.
- You will begin developing strategies for a business and marketing plan.

There is more to starting a new business endeavor than coming up with a great idea and then jumping feet first into the project. Often the success of a new business is predetermined before the project is ever started. Careful and thoughtful planning lay the essential groundwork needed to give a new business a reasonable chance of succeeding.

The planning process is divided into several steps essential to successful business planning. Each step of the process needs to be thoughtfully examined, and adequate resources of time and money need to be allocated to develop each of the following areas:

- Idea
- Organization
- Feasibility
- Planning
- Capital
- Marketing

Idea

How do you determine if a high-tunnel production operation is really worth the effort necessary to turn it into an enterprise? The answer to this question depends on your level of basic knowledge about the business and the ability to turn that knowledge into a profitable business venture.

It is critical to do an early and accurate self-assessment of the business climate for high-tunnel production in your area. This early analysis is an important step in building confidence and knowledge of the enterprise and will be critical in securing business partners, financing and even customers.

Taking the time to build a strong understanding of high-tunnel fruit and vegetable production at this stage provides some of the most affordable risk management available. Detailed business plans and marketing strategies will come later; this process is designed to simply improve your basic understanding of high-tunnel production and management.

Organization

One of the most important decisions entrepreneurs make is how to legally set up their businesses. The choice can be a wise move or a costly mistake with regard to taxes paid, protection from liability and the amount of flexibility in running the operation. Whether the enterprise is a stand-alone operation or simply an addition to an existing business, it is important to carefully consider how the project impacts the business structure.

The initial choice of a business structure, even if it achieves optimum results in the start-up phase, may require adjustment or alteration as the business matures. It is important to Periodically re-examine the appropriateness of the type selected.

The most common types of formal business structures are as follows:

- Sole Proprietorship
- Cooperative
- General Partnership
- Limited Partnership
- Limited Liability Partnership
- Limited Liability Company
- Corporations

The form of organization you select depend the following factors:

- Capital structure.
- Tax considerations.
- Management method.
- Risk management/Liability.
- Number of people associated in the venture.
- Kind of business or operation.
- Cost and formality of the organization.
- Ability and/or desire of owners to isolate personal assets from claims of the business' creditors.
- Perpetuation of the business.

Sole Proprietorship
This is the easiest and least costly way of starting a business. A sole proprietorship can be formed by finding a location and opening the door for business. There are likely to be fees to obtain business name registration, certificate and other necessary licenses. Attorney's fees for starting the business will be less than the other business forms because less preparation of documents is required and the owner has absolute authority over all business decisions.

Cooperative
A cooperative business belongs to the people who use it. The member/owners use the cooperative as a source for the goods and services they need. Member/owners share in the control of their cooperative, meet at regular intervals, review detailed reports and elect directors from among themselves. In turn, the directors hire management to oversee the day-to-day affairs of the cooperative in a way that serves the members' interests.

General Partnership
A general partnership can be formed simply by an oral agreement between two or more persons, but a legal partnership agreement drawn up by an attorney is highly recommended. Legal fees for drawing up a partnership agreement are higher than those for a sole proprietorship but may be lower than incorporating. A partnership agreement could be helpful in solving any disputes. However, partners are responsible for the other partner's business actions, as well as their own.

Limited Partnership
Limited Partnerships are much the same as Limited Liability Companies (see Limited Liability Company on next page) but must include one partner (the general partner) having unlimited liability for the debts of the partnership. Special rules govern whether a corporate general partner is carrying enough risk to qualify the entity as a partnership versus a corporation for tax purposes.

Limited Liability Partnership
Limited Liability Partnerships (LLPs) are general partnerships that have chosen LLP status. Partners of an LLP have unlimited liability for their own actions but limited liability for the actions of their partners. LLP status may work for businesses that have typically been conducted as general partnerships and whose partners now wish to limit their potential liability for each others' actions. Special rules govern the LLP election by partnership of licensed professionals.

Limited Liability Company
Limited Liability Companies (LLCs) are a hybrid form of entity that combines some characteristics of a corporation with other characteristics of a partnership. The LLC offers limited liability for all of its members and the option of centralized management (which the LLC may choose not to adopt). The LLC also offers partnership tax status with flexibility in handling varied contributions and types of capital. The LLC requires a tailored agreement that spells out all details, while corporations may often be formed with standardized documents.

Corporations
Think of a corporation as legally separate from its shareholders. This is the most important feature distinguishing it from a partnership or proprietorship. It is definitely best to seek legal counsel when setting up a corporation. This type of business is usually the most costly to form, especially if organizational problems are complex. People usually incorporate to limit personal liability for the debts and liabilities of the business. However, with many new businesses, this limit of personal liability applies only to judgments brought against the company for negligence, defective products or frivolous suits.

A corporation is a separate legal entity and a more structured form of business. It can continue to function even without the existence of original ownership or other key individuals. It also has advantages in terms of enabling employees to participate in various types of insurance and profit sharing. A corporation has more flexibility in terms of different approaches to taxation.

Feasibility
A feasibility study can take on many shapes and sizes and is often confused with a 'business plan.' Although various components are common to both the feasibility review and the business plan, not all of the information developed in the feasibility review will be incorporated into a business plan and vice versa. The feasibility review of an individual enterprise such as a high tunnel will differ greatly from a feasibility study for a large start-up production facility, but what they do have in common is that they offer a reality check on the merit of the business idea. To evaluate the validity of a high tunnel enterprise, take steps to remove personal emotion from the evaluation process. It is wise to utilize and/or engage an independent third party to help with the process, which might best be described as "getting a second opinion."

Figure 1. Blackberries have proven to be a productive and high value crop when grown in high tunnels.

In this process, an exhaustive set of questions should be developed to help validate the core business principles behind utilizing a high tunnel for fruit and vegetable production. The process should identify opportunities, unexpected hurdles and other impacts that might be encountered. A typical feasibility review will look at five areas of impact:

1. Local Impact
2. Market
3. Technical Resources
4. Financial Projections
5. Management

Examples of questions that should be asked for each category are as follows:

Local Impact

- Are adequate local resources available to support a high tunnel business, including production specialists, equipment suppliers, wholesalers, etc?
- Will there be negative impact or resistance to a high tunnel operation?

Market

- Is there a clearly identifiable and measurable market(s) that helps identify what to grow, how much to raise, where to sell, at what prices, etc?
- Will the location of the business appropriately serve the market? How far and how often will you have to travel? What are the transaction costs?

Technical Resources

- Is there access to quality equipment and service to address the unique growing environment created by high tunnels?
- Can the infrastructure needs be met, including adequate site location, easy access, amble water, ventilation, etc.

Financial Projections

- Do market projections and production assumptions match, and at a profitable level?
- Are adequate resources available to operate in both good and bad business climates?
- Can all potential costs be identified through detailed production budgets?

Management

- Is there enough experience to manage the business?
- Are all area of the business adequately covered? Managers don't always make good growers and growers don't always make good marketers.
- Are adequate support services available to assist management?

Planning

At this point, it is important to develop a written business/operating plan for the enterprise with all the details of operating and managing the high tunnel project. Having a well-written document provides many benefits from helping to secure financing to providing a road map to keep the project on track. Numerous books and online tools are available to simplify the process of writing and organizing a business plan. No matter what format process you use, a good business or enterprise plan should, at a minimum, do the following:

- Adequately describe the business, its structure, its products and its goals.
- Explain the roles and responsibilities of all involved.
- Outline the marketing plan and strategies to remain relevant.
- Illustrate the financial plan, including the assumptions and goals used to reach profitability.

Capital

The search for financing is similar to any other aspect of your business; it takes time and effort to research the sources right for you. Begin by examining your needs, planning how the funding will be utilized and studying what is available. The ability to secure sufficient funds to start and grow your high tunnel enterprise depends largely on your preparation and demonstrated capacity to manage those funds efficiently and effectively. While poor management is cited most frequently as the catalyst for business failures, inadequate or ill-timed financing is a close second. It is simply not enough to have sufficient financing. You need to have the knowledge and planning ability to manage it well. That means avoiding such common mistakes as securing the wrong type of financing, overestimating or underestimating the amount required or the cost of borrowing money, and then finding it difficult to repay.

If financing is required, check for local funding first. Many rural development groups have established modest revolving loan funds or small grant programs to encourage local businesses. Local lenders are frequently very aggressive in helping with business startups within their lending territories. Also, some level of local participation is frequently a requirement for state and federal grant and guaranteed lending programs.

Marketing

Marketing is a "first, last and always" consideration.
Before production starts, make sure a market has been established. Too many businesses discover too late that the world will not necessarily beat a path to their door just because they offer a better mousetrap. Although the product may be the best on the market, a good marketing program is essential for a business venture to realize its fullest potential and profit.

Figure 2. Farmers' markets are an option for retail marketing.

The best marketing strategy will yield whatever level of sales it takes to make a business profitable. The best marketing strategy for any business venture calls for a thorough understanding of the needs of the potential buyers and for the business' ability to differentiate and diversify as markets change.

When developing a marketing strategy for high tunnel production, the strategy should capitalize on one or more of the benefits that high tunnels offer over traditional production methods. Some of those benefits include:

- *First to market* - This advantage disappears quickly, and along with it, any premiums that a customer is willing to pay.
- *Multiple crops* - A well managed production schedule can benefit from multiple crops.
- *Quality* - Well-managed high tunnels should have less disease issues to deal with, resulting in more uniform and appealing products.
- *Unique crop* - High tunnels provide an opportunity to produce niche crops that otherwise do not grow well using traditional production methods. The flip side of this is the products may not be as common and therefore demand may be less.
- *Scalability* - High tunnels provide risk management for customers who demand consistent and predictable volumes and quality.

What many entrepreneurs fail to recognize is that customer 'needs' change. Sometimes these changes are over a period of years, sometimes during the season or even week to week, making it critical to have a marketing plan that is adaptable to those changing needs. However, changes to a marketing plan need to be done systematically to avoid negatively impacting the business' ability to remain profitable. A good marketing plan has an ongoing evaluation process that will include the following components:

Identification - Methods should be established to constantly scan the marketplace for areas of threat or opportunity.

Analysis - Marketing priorities are set based on 'potential' customer demands. Priorities can be established by asking six questions:

1. How quickly will the marketing opportunity/threat develop?
2. How will it impact our products and operations?
3. How likely is it that it will become of major importance?
4. How would our investors expect us to act in relation to this marketing opportunity/threat?
5. What is our ability to react to this opportunity/threat?
6. What are the costs of not reacting to it?

Obviously, those opportunities/threats with the greatest bottom-line impact need to be addressed within the overall marketing plan as quickly as possible. This is extremely challenging in a high tunnel production system when changes can often only be made once a season/year. However, high tunnel production does allow an opportunity to get product to market slightly earlier and longer than traditional producers. Developing a production schedule that maximizes these advantages will be critical to maximizing profitability.

- *Strategy* - Develop a written strategy to address changes in the market place that directly impact or change the original plan.
- *Action* - Marketing activities are a synchronized and integrated response to the nature of the marketplace. A marketing campaign constantly coordinates all available business capabilities. Some marketing activities might be short-lived while others might carry on over a longer period. But it is always advisable to have more than one market outlet or one market strategy.
- *Evaluation* - Regularly monitor and measure any changes to the original marketing strategy to evaluate the impact of those changes on profitability.

Market Diversity

The marketing strategy in any business should not be highly dependent on one venue or one market outlet, and when possible, not on one product. Any number of factors including customer needs, product quality or even inventory can change the market dynamics. Being able to quickly shift product from one market channel or venue to another can make the difference between profit and loss. Developing and participating in multiple markets provides significant risk management as well as market research. The challenge is to select and exploit the market channel that best fits your high tunnel production and profit goals. Participate in other markets to the extent that those markets offer you benefit through additional income, added risk management, inventory reduction, market knowledge or relationship building.

Pricing

Although the producer can set the price, the consumer controls the price. To that end, producers have two principles of business management that they must have complete control and knowledge of:

1. What is your total cost of production?
2. What is the competitor's price?

Understanding these two components provides the ability to effectively analyze a marketing strategy and also to make sound business decisions regarding future production.

Assignment

Complete "Business Planning and Marketing for High Tunnels" worksheet, found in Appendix A4 on page 67 - 69.

Appendix A1

Compost Application Problem

You decide to apply fertilizer to your high tunnel before you plant a tomato crop. The nitrogen recommendation is 60 pounds per acre. Because you are an organic grower, you choose to use wind-rowed, composted bedded cattle manure from a producer in Northwest Iowa.

You may have the following questions:

1. **How many gallons of compost do I need for the high tunnel?**

2. **What depth, in inches, is the compost over the surface area?**

3. **What is the tons per acre equivalent?**

What you know:

High tunnel dimensions are 21 feet wide and 96 feet long.

United States Composting Council (USCC) guidelines indicate that 20 percent of the nitrogen in compost will be available for plant uptake the first year, 5 percent the second year and 2 to 3 percent the third year.

1 cubic yard = 182 gallons

1 inch of surface compost over 1,000 square feet = 3.1 cubic yards

Composted bedded cattle manure analysis is:

- 27 percent moisture (or 63% solids by weight)
- Bulk density = 4.85 pounds per gallon (different than soil bulk density, which is expressed as a unit of dry soil. Compost bulk density = weight of compost/ volume of compost on an ‘as is’ basis, i.e., wet weight basis)
- pH = 5.4   Ec = 3.5 dS/m   C:N ratio = 14:1
- Elemental analysis, dry weight basis:

N = 1.4%	P = 0.63%	K = 0.38%	Ca = 5.61%	Mg = 0.43%
S = 0.31%	Na = 0.08%	B = 19 ppm	Zn = 172 ppm	
Cu = 23 ppm	Mn = 343 ppm		Mo = 3 ppm	

Hint: *First calculate how many pounds of available nitrogen are in the wet compost. Remember, use the USCC guidelines for nitrogen release in the first year of application.*

Appendix A2

Inorganic Fertilizer Application Worksheet

You decide to apply fertilizer to your high tunnel before you plant a tomato crop. The nitrogen recommendation is 60 pounds of nitrogen per acre. The phosphate (P_2O_5) is 120 pounds per acre and potash (K_2O) is 300 pounds per acre. (This soil test recommendation indicates the soil sample was deficient in phosphate and potash).

The soil test report might even suggest a fertilizer grade, say, 5-10-10 or 13-13-13. These numbers show the percentage of nitrogen, phosphate and potash, respectively. Thus, a 40-pound bag of 13-13-13 contains 5.2 pounds of each of the nutrients (40 × 0.13). But, in our situation, the recommendation calls for a ratio of 1-2-5 (the phosphate and potash recommendation divided by the nitrogen amount), not a 1-1-1. Some common and close fertilizer products would be 6-24-24 (a 1-4-4) or 8-16-32 (1-2-4). Thus, you would have to purchase the individual components and weight them yourself. On a large, field scale, the local co-op or fertilizer dealer would likely perform the bulk blending for you.

Remember, for small quantities, use the following weight-to-volume relationship:

Material	Weight	Volume, pints
Mixed fertilizers (10-6-4, 13-13-13, etc.)	1	1
Superphosphate (0-46-0)	1	1
Muriate of potash (0-0-60)	1	1
Urea (46-0-0)	1	1 1/3
Ammonium nitrate (34-0-0)	1	1 1/3
Sulfate of potash (0-0-50)	1	3/4
Ground limestone	1	3/4

What you know:

1 acre = 43,560 square feet (ft^2)

High tunnel dimensions = 21 feet × 96 feet = 2,016 square feet

1. **How much nitrogen, phosphate and potash do you need to broadcast over the surface and till to a 4- to 6-inch depth before laying plastic and trickle tubing and planting the crop?**

Appendix A3

High Tunnel Row Design Worksheet

You can use your existing high tunnel(s) to do the calculations and comparison or use a 30-foot × 96-foot high tunnel for this exercise.

Things you know:

1. High tunnel space available (the area under the high tunnel: width × length).
2. Select a crop you plan to grow or use an example of tomatoes in half, cucumbers (trellised) in the other half.
3. Plastic mulch spaced at least 4 feet apart center-to-center.

From what you have learned in the chapter and information given on Table 1 (page 50), determine the best spring season planting (bed/row) arrangement. Use the diagrams below to plot both longitudinal and lateral bed/row arrangement.

	Lateral rows	**Longitudinal rows**
Linear feet of plastic mulch needed?		
What percent of the high tunnel space is utilized in crop production?		
How many rows of tomatoes? What is the total linear feet of tomatoes or the crop that you are growing?		
How many transplants are needed?		
How many rows of cucumbers? What is the total linear feet of cucumbers?		
How many cucumber plants are needed?		

Appendix A4

Business Planning and Marketing Worksheet

Instructions: Complete the following worksheet questions. All of the questions are key considerations that need to be addressed in preparation for developing a comprehensive business and marketing plan.

Business Summary
In this section, provide a summary of your business plan in no more than 250 words. Some people would call this their elevator speech when asked, “What do you do?” **In this case, how would you explain your business to someone who has no knowledge of you or high tunnels? Can you answer any of these questions:**

- **Identify the need you’re filling?**
- **How do you plan to fill it?**
- **Why are you the right person to fill it?**

Local Economic Impact

1. What is your vision for this high tunnel venture?

2. Are adequate local resources available to support a high tunnel business, including production specialists, equipment suppliers, wholesalers, etc?

Market

1. What have you identified as your target market and market area? (Identify your market area, possibly city, county, metro area, region, state, interstate, national, Internet, etc.)

2. What are the demographics of customers in your market area? (List the demographic categories that are important to your market, possibly age, income, ethnicity, commuter, industry, etc. [Demographics Data: http://www.iowadatacenter.org/ and www.marketmakeriowa.com])

3. How do you plan to differentiate your products and services from the competition?

Technical

How did or will you determine your production goals and/or income benchmarks? (Explain how projected production and/or income will be met.)

Financial

1. How will you maintain your business and production records?

2. What system(s) will be used and who will be responsible for keeping them current?

Management

1. What technical experience do you have that strengthens the enterprise? What additional help or services will you need and where will you find it. In the table provided below, list the roles and responsibilities of any other people who are involved.

Business Team	Contact	Phone	Email
* Insurance Provider			
* Finance Source			
* Specialist			

2. In the table provided below, identify and list at least five factors that are critical to the success of your business.

1	
2	
3	
4	
5	

Appendix B

Worksheet Answers

Compost Application Worksheet (page 64)

1. How many gallons of compost do I need for the high tunnel?

Nitrogen = 1.4% on a dry weight basis. Only 63% solids, so 0.88% N on wet basis (1.4 × 0.63). But only 20 percent is available the first year.

The tunnel square feet = 21 × 96 = 2,016 square feet (SF)
Nitrogen rate = 60 pounds per acre and only 2,016 SF,
so 2,016/43,560 SF in an acre = 0.046 acres in the tunnel.

Therefore, the amount of nitrogen needed is **60 × 0.046 = 2.76 pounds**

Using a general string formula:
4.85 pounds per gallon (bulk density of compost) × 0.63 (% solids) × 0.14 (% nitrogen) × 0.2 (% nitrogen available first year) = 0.00856 pounds nitrogen per gallon available
2.76 pounds nitrogen needed

2.76/0.00856 = **322.4 gallons compost to spread in the tunnel**

2. What is the depth of the compost, in inches, over the surface area?

Using what you know, the 322 gallons of compost = 322/182 gallons per cubic yard = 1.78 cubic yards
The number of 1,000 SF units in the tunnel = 2,016/1,000 = 2.016
1.78/2.016 = 0.88 cubic yards per 1,000 SF

0.88/3.1 cubic yards per 1 inch = 0.29 inches or approximately **1/4 to 1/3 inch**

3. What is the tons per acre equivalent?

Caution:
Many growers apply by 'sight.' Note that if you covered the surface area to a 1-inch depth, you would be adding three to four times the nutrients, and thus, the salts. The nitrogen amount would increase to 240 pounds per acre. Way too much! One high tunnel grower applied 1 inch of compost over the tunnel area and added 441 pounds of nitrogen, 1,345 pounds of phosphate and 1,559 pounds of potash! Use soil test interpretation and recommendations as guidelines.

Inorganic Fertilizer Application Worksheet (page 65)

How much nitrogen, phosphate and potash do you need to broadcast over the surface and till to a 4- to 6-inch depth before laying plastic and trickle tubing and planting the crop?

Because the recommendation is given in acres, figure the acres in the tunnel. Therefore, 2,016 ÷ 43,560 = 0.046 acres in the tunnel.

Nitrogen needed (from urea) = 60 pounds per acre recommended ÷ 0.46 × 0.046 = **6 pounds of urea**

Phosphate (from 0-46-0) = 120 pounds per acre recommended ÷ 0.46 × 0.046 **= 12 pounds of superphosphate**

Appendix C

Useful Conversions and Measurements

Linear
1 mile (mi) = 1,760 yards (yd) = 5,280 feet (ft) = 1.61 kilometers (km)
1 yard (yd) = 3 ft = 0.9144 meters (m)
1 foot (ft) = 12 inches (in) = 30.48 centimeters (cm)
1 centimeter (cm) = 0.3937 in
1 kilometer (km) = 0.6124 mi
1 rod = 16.5 ft
1 meter = 100 cm = 3.281 ft = 39.937 in = 1.094 yd
40 rods = 1 furlong

Area
1 square mile = 640 acres
1 square acre = 4,840 square yard = 43,560 square feet (sq ft) = 0.45 hectare
1 square inch = 6.45 square centimeters
1 square yard = 9 sq ft = 0.914 square meters
1 hectare = 2.471 acres
Area of a circle = radius squared x 3.1416 or diameter squared x 0.7854
Area of a rectangle = length x width area of a triangle = (base x height) ÷ 2

Volume
Vertical round tank = 3.1416 x radius squared x height = cubic feet (cu ft)
Volume (cu ft) x 7.4805 = gallons (gal)
Cylinder = 3.1416 radius squared x height
1 bushel (bu) = 4 pecks = 32 quart (qt)(dry) = 1.25 cu ft
1 cord (wood) = 128 cu ft = 4 ft x 4 ft x 8 ft
1 cubic yard = 27 cu ft
1 cubic foot = 1,728 cu in = 7.48 gal or 0.8 bu
1 cubic yard = 182 gal
1 gal = 0.1337 cu ft = 231 cu in

Liquid or Fluid Volume
1 teaspoon (tsp) = 1/6 fluid ounce (fl oz) = 0.17 fl oz ≈ 5 cubic centimeters (cc)
3 tsp (level) = 1 tablespoon (tbsp) = 0.5 fl oz ≈ 15 milliliters (ml)
1 tbsp = 3 tsp = 0.5 fl oz ≈ 15 cc
2 tbsp = 1 fl oz = 1/8 cup = 29.57 cc
8 fl oz = 1 cup
16 fl oz = 2 cups = 1 pint (pt)
32 fl oz = 2 pt = 1 quart (qt) = 32 fl oz = 0.9463 liters (L)
1 cup = 16 tbsp = 8 fl oz = 0.5 pt
1 gallon (gal) = 128 fl oz = 4 qt = 3.785 L = 3,785 ml
1 L = 1.057 qt
1 cubic ft = 7.48 gal
1 acre inch = 27,150 gal

Weight
1 ounce (oz) = 28.35 gram (g)
1 pound (lb) = 16 oz = 453.6 g = 0.454 kilogram (kg)
1 gallon (gal) water = 8.345 lb
2.205 lb = 1 kg = 1,000 kg
1 ton = 2,000 lb = 907 kg
1 acre furrow slice (plow depth ≈ 6 inch soil depth) ≈ 2 million lb ≈ 21,780 cubic feet = 806.7 cubic yards
1 quintal/hectare = 89.216 lb/acre
1 lb/acre = 1.12 kg/hectare
1 short ton = 0.91 metric tons

Fertilizer Weights and Volumes

Material	Weight	Volume, pints
Mixed fertilizers (10-6-4, 13-13-13, etc.)	1	1
Superphosphate (0-46-0)	1	1
Muriate of potash (0-0-60)	1	1
Urea (46-0-0)	1	1 1/3
Ammonium nitrate (34-0-0)	1	1 1/3
Sulfate of potash (0-0-50)	1	3/4
Ground limestone	1	3/4

Compost
1 inch of surface compost over 1,000 square feet = 3.1 cubic yards

Spray Concentration

Mix Size	0.5 v/v	1% v/v	2% v/v
1 gallon	0.64 fl oz or 19 ml	1.28 fl oz or 38 ml	2.56 fl oz or 76 ml
2 gallon	1.28 fl oz or 38 ml	2.56 fl oz or 76 ml	5.12 fl oz or 151 ml
3 gallon	1.92 fl oz or 57 ml	3.84 fl oz or 114 ml	7.68 fl oz or 227 ml

1% solution = 1% volume/volume (v/v) = 10,000 parts per million (ppm) = 1.28 fluid ounces/gallon

Quick Conversions
1 pint (pt)/acre = 0.46 fluid ounces (oz)/1,000 square feet (sq ft)
1 pound (lb)/acre = 0.37 oz/1,000 sq ft = 1.12 kilograms (kg)/hectare
1 quart/acre = 0.73 oz/1,000 sq ft = 1.5 tablespoons or 4.5 teaspoons (tsp)/1,000 sq ft = 22 cubic centimeters or ml/1,000 sq ft
1 ton/acre = 45.0 lb/1,000 sq ft
1 kg/hectare = 0.892 lb/acre
1 oz/1,000 sq ft = 2.72 lb/acre
1 pt/100 gallon (gal) = 0.25 tsp/gal
1% volume/volume (v/v) = 1 gal/100 gal
1 lb/100 gal = 1.6 oz/gal
1 mile per hour (mph) = 88 ft/minute
1 knot = 1.1516 mph

Temperature Conversions
Temperature (°F) = (°C x 1.8) + 32
Temperature (°C) = (°F-32) x 0.555

For assistance and easy conversions, go to: **smartconversion.com**

Appendix D

Tensiometer Tips for Vegetables

By Henry G. Taber
Professor and Extension Vegetable Specialist, Iowa State University

How do they work?

The key to the tensiometer is the sensitive gauge. You should handle them very carefully and be sure not to drop or bump the gauge. Be sure you store them properly during the winter so that they never freeze. The tiny water droplets left in the gauge after a season's use will ruin the sensitive measurement when frozen.

As the soil dries out, water is sucked out through the porous ceramic tip, creating a partial vacuum inside the tube that is read on the vacuum gauge. As the soil continues to dry out, the soil suction withdraws water from the tensiometer, increasing the gauge reading.

When the soil is irrigated or rainfall occurs, soil suction is reduced and water is drawn back into the tensiometer by vacuum. This reduces the vacuum and the gauge reading is lowered.

Figure 1. Experts recommend that producers take tensiometer readings at two depths.

What do the numbers mean?

The reading shows the relative wetness of the soil. The higher the reading, the drier the soil. The numbers from 0 to 100 are called centibars (cbars). One hundred centibars equals 1 bar, which is equivalent to 1 atmosphere. A tensiometer can operate effectively within a range of 0 to 80 centibars (Figure 1).

A zero reading indicates a saturated soil in which plant roots will suffer from lack of oxygen. Zero to 5 cbars is too wet for most crops. The range from 10 to 25 represents ideal water and aeration conditions. As readings go higher than 25, water deficiency may occur for sensitive plants having shallow root systems, such as plants growing on coarse-textured soils.

Figure 2. The gauge on the left indicates a drier condition (higher reading) than the gauge on the right (a low reading, less than 10 cbars).

Updated June, 2006

How should they be installed?

- Fill the tensiometer with tap water and soak for 24 to 48 hours in a bucket of water.

- Apply a strong vacuum with the hand vacuum pump to remove trapped air. The vacuum should be drawn up to 80 centibars, usually for 5 or 6 quick pulls. Do this with the ceramic tip below the water surface. There should be a few air bubbles emerging. Repeat this procedure until all air is removed from the instrument. You may have to soak for an additional 24 hours. Replace the cap with stopper, but do not over tighten. Be sure to transport to the field by protecting ceramic tip from air-drying either in the bucket of water or plastic tied around the tip.

- Drive a half-inch conduit pipe, or use a soil sampling test tube, to within 1-inch of the depth that the tensiometer will be installed (Figure 3). Add a little water to the bottom of the hole to allow the soil to soak up and make firm contact between the ceramic tip and surrounding soil. Insert tensiometer into hole and gently push down the remaining 1-inch to make a firm soil-ceramic cup contact (Figures 4 and 5).

- Where the tensiometer comes out of the ground, be sure you mound up soil to prevent a depression and water running down the side of the tube during an irrigation or rain.

- Don't let the gauge touch the soil. The rubber bottom of the gauge needs to expand and contract to allow an accurate reading.

Figure 3. Use a soil probe or half-inch conduit pipe to make hole to the correct depth.

Figure 4. Add a small amount of water to the bottom of hole for good contact of ceramic cup to soil.

Figure 5. Firm the soil around the base of the tensiometer so that rain water does not run down the side of the tube and distort your reading.

After placing, when can they be read?
Twenty-four hours is long enough to obtain a reading after installation. If it is a brand new tensiometer, and under favorable soil conditions, a correct reading may be obtained in 30 minutes. You can improve the response time of an old ceramic cup tensiometer by lightly sanding the surface.

When should readings be taken?
Always read the tensiometer at the same time of day. If possible, an early morning reading is best because plants and soils have reached a condition near equilibrium. Water movement in plants and soil at that time has almost stopped.

A minimum of three readings should be taken between irrigations. Take readings frequently enough so that change from one reading to the next is not greater than 10 to 15 centibars. With trickle irrigation systems, daily readings are necessary.

How many do you need?
The crop and soil texture will be the main determining factors. There should be at least one, preferably two, locations for each change of crop and field or soil texture.

The depth to place the tensiometer and how many are needed at each location depends on the crop-rooting pattern. Only one tensiometer will be needed for plants rooting less than 15 inches. They should be placed between plants in a row and in the active root zone. The shallow-depth tensiometer should be placed at about 6 inches deep for shallow-rooted crops (peppers, lettuce, onions) and at 8 to 12 inches for deep-rooted crops (tomatoes, melons, sweet corn). The second tensiometer should be installed about 12 inches deeper than the first one.

Approximate cost?
Depending on the length (6 inches to 3 feet) and the company source, tensiometer costs may run from $55 to $75 each. Two major manufacturers are:

Irrometer Company
PO Box 2424, Riverside, CA 92516
Phone: 909-689-1701
irrometer.com

Soil Moisture Equipment Corp.
Santa Barbara, CA
Phone: 805-964-3525
soilmoisture.com

At what readings should I irrigate?

This depends on the crop, soil type and irrigation method. With overhead irrigation, do not irrigate when readings are in the 0 to 10 range because the soil is too wet and plant roots may suffer a lack of oxygen. In most field conditions, irrigation is not needed in the 10 to 25 range, but do not delay irrigation much after readings reach 75 to 80 because the soil has become quite dry. To evaluate a wider soil moisture range for overhead irrigation, consider using Watermarks. They are effective in the range of 20 to 200 cbars. Watermarks are similar to tensiometers and maintenance free but require a hand-held meter to take the readings. Listed below is a chart to begin irrigation when using overhead sprinklers on a fine-textured soil type.

Crop	Reading
Tomatoes	60-70
Melons, carrots	50-60
Lettuce	40-50
Strawberries	25-30

With drip or trickle irrigation, the objective is to maintain readings within the 10 to 25 range by controlling the amount of water applied. This may mean daily application or more frequent for sandy soils because you are only wetting a portion of the root zone. Thus, for trickle irrigation allow only 20 to 30 percent soil water depletion from the field capacity level. Tensiometers readings will rise about 12 to 18 cbars.

Soil Type	Field Capacity, cbars
Sandy, loamy sand	7-12
Loam, silt loam	12-20
Clay loam	20-35

Begin irrigation when the shallow tensiometer records about 12 to 18 cbars higher than the field capacity set point for the soil type listed in the table. This value being equivalent to about 25 percent depletion of available water. For a loam, the trigger point to begin irrigation would be about 30. The deep tensiometer should record about 10 cbars between irrigations. If the deep tensiometer drops to zero, you have applied too much water. Conversely, if it continues to rise between irrigations, you have not applied enough water.

How many gallons should I apply?

This answer depends on the crop rooting depth and water-holding capacity of your soil type. You can obtain this information from your local Farm Service Agency (formerly the Soil Conservation Service) that maintains the county soil survey maps. For example, a Clarion silt loam has a water-holding capacity of 2.4 inches per foot. Consider the following:

<u>Pepper crop wetted volume</u> - Clarion loam soil type (holds 2.4 inch available water/foot)

Rooting depth = 1.0 feet
Bed spacing = 6 feet (equivalent to 35 rows per acre), which gives 7,315 linear feet per acre
Wetted radius of bed = 16 inches (or 32 inches width)
Thus, 2.67 feet × 7,315 linear feet = 0.45 acres of plastic or wetted portion

Now, rooting depth available water = 1 foot × 2.4 inches water/foot = 2.4 inches water/foot/acre
1 acre inch = 27,000 gallons
27,000 gals × 2.4 inches = 64,800 gallons for full water capacity of the soil profile per acre
We only have 0.45 acres under plastic that is wetted.
Thus, 0.45 × 64,800 gals = 29,030 gallons needed for full soil capacity.
If we turn on the pump when the tensiometer reaches 25 to 30 cbars (25% depletion), we would need to apply 29,030 × 25 percent = 7,258 gallons or about 7,300 gallons.

Should I record readings?

Yes, it is best to record the readings on charts provided by the manufacturer of the tensiometer. The chart lines will show the wetting/drying of the soil and give you an advance indication of what you can expect in a few days. This will help you plan for the next irrigation or to see if a previous irrigation failed to penetrate adequately to the root zone.

How do I know when the tensiometer is not working?

An instrument out of water or leaking will remain at zero. Two or more days of successive zero readings are a sign of malfunction. Unscrew the cap with stopper and add more water to the reservoir. A yellow pencil helps in the flow of water down the tube to the ceramic cup.

Appendix E

References and Resources

Iowa State University

Horticulture Extension Commercial Vegetable Crops
public.iastate.edu/~taber/Extension/index.htm

Horticulture Research Station
55519 170th Street
Ames, IA 50010
Phone: 515-232-4786
ag.iastate.edu/farms/hort.php
Email: nhowell@iastate.edu

Iowa State University Extension Online Store (Publications)
119 Printing and Publications Building
Iowa State University, Ames, IA 50011
Phone: 515-294-5247, Fax: 515-294-2945
extension.iastate.edu/store/
Email: pubdist@iastate.edu

Iowa State University Soil and Plant Analysis Laboratory
G501 Agronomy Hall
Iowa State University, Ames, Iowa 50011-1010
Phone: 515-294-3076 Fax: 515-294-5567
agron.iastate.edu/soiltesting
Email: soiltest@iastate.edu

Iowa State University Extension Value Added Agriculture Program
1111 NSRIC
Iowa State University, Ames, IA 50011-3310
Phone: 515-294-9483, Fax: 515-294-9496
extension.iastate.edu/valueaddedag
Email: swoods@iastate.edu

Leopold Center for Sustainable Agriculture
9 Curtiss Hall
Iowa State University, Ames, IA 50011-1050
Phone: 515-294-3711, Fax: 515-294-9696
leopold.iastate.edu
Email: leocenter@iastate.edu

Market Maker
marketmakeriowa.org

AgMRC
agmrc.org/

Plant and Insect Diagnostic Clinic
327 Bessey Hall
Iowa State University, Ames, IA 50011
Phone: 515-294-0581
plantpath.iastate.edu/pdc/

Iowa Department of Agriculture and Land Stewardship

agriculture.state.ia.us/

Agricultural Diversification and Market Development Bureau
Wallace State Office Building
502 E. 9th Street, Des Moines, IA 50319
Phone: 515-281-5321
iowaagriculture.gov/agDiversification.asp
Email: AgDiversification@iowaAgriculture.gov

Horticulture and Farmers' Market
Wallace State Office Building
502 E. 9th St., Des Moines, IA 50319
Phone: 515-281-8232 Fax 515-242-5015

Organic Certification Program
iowaagriculture.gov/AgDiversification/organicCertification.asp
Email: AgDiversification@iowaAgriculture.gov

Pesticide Bureau
Wallace State Office Building
502 E. 9th St., Des Moines, IA 50319
Phone: 515-281-4339
iowaagriculture.gov/pesticides.asp
Email: pesticides@iowaAgriculture.gov

State Apiarist
Andrew Joseph
Iowa Lab Facility – Entomology and Plant Science
2230 S. Ankeny Blvd, Ankeny, IA 50023
Phone: 515-725-1470
iowaagriculture.gov/Entomology/beekeepingInformation.asp

Soil and Plant Tissue Analysis

Waters Agricultural Laboratories
Calhoun Rd, Hwy 81
Owensboro, KY 42301
watersag.com

A & L Great Lakes
3505 Conestoga Drive
Fort Wayne, Indiana 46808
Phone: 260-483-4759
algreatlakes.com/index.asp

MVTL Laboratories
51 L Avenue
Nevada, IA 50201
mvtl.com

Midwest Laboratories
136 B. Street
Omaha, NE 68144
midwestlabs.com

Iowa State University Soil & Plant Analysis
G501 Agronomy Hall
Iowa State University, Ames, IA 50011-1010
Phone: 515-294-3076
agron.iastate.edu/soiltesting/howto(menu).htm

For a list of additional certified soil testing labs,
Go to: iowaagriculture.gov/feedAndFertilizer/
certifiedSoilTesting.asp

Organizations

American Society for Plasticulture
174 Crestview Drive, Bellefonte, PA 16823
Phone: 814-357-9198, Fax 814-355-2452
email: info@plasticulture.org
.plasticulture.org

Buy Fresh Buy Local
For local chapters, go to: foodroutes.org/buy-fresh-buy-local.jsp

Iowa Fruit and Vegetable Growers' Association
P.O. Box 1202 Ames, IA 50010-1202
Phone: 515-232-5801, Fax 877-262-4516
Email: ifvga@q.com
iafruitvegetablegrowers.org/

Iowa Honey Producers Association
President: Donna Brahms
65071 720th St., Cumberland, IA 50843-8125
Phone: 712-774-5878

Midwest Organic and Sustainable Education Service (MOSES)
PO Box 339, Spring Valley, WI 54767
Phone: 715-778-5775, Fax: 715-778-5773
mosesorganic.org

Practical Farmers of Iowa
137 Lynn Avenue, Suite 200, Ames, Iowa 50014
Phone: 515-232-5661, Fax: 515-232-5649
practicalfarmers.org/

United States Composting Council
1 Comac Loop 13 B1, Rokonkoma, NY 11779
Phone: 631-737-4931
compostingcouncil.org/

Websites

Hightunnels.org
hightunnels.org
This website contains valuable information on high tunnels for growers and educators with an extensive list of resources on the planning, construction and production practices in high tunnels as well as sources of supplies.

The Penn State Center for Plasticulture
plasticulture.cas.psu.edu

Publications

Bachmann, Janet. 2009. Market Gardening: **A Start Up Guide. National Sustainable Agriculture Information Service.** Online at: attra.ncat.org/attra-pub/marketgardening.html

Jett, Lewis, David Coltrain, Jay Chism, James Quinn and Andrew Read. 2004.
High Tunnel Tomato Production Guide. (Publication M170) For sale from University of Missouri Extension, Cost is $10. To order, call: 800-292-0969 or online at: extension.missouri.edu/publications/DisplayPub.aspx?P=M170

Lamont, William. 2006. ***Implementation of a BioControl Program for Insect Control in High Tunnels.*** Pennsylvania State University. Cost is $10.00 (includes tax)
Mail order and check to: Dr. Bill Lamont, Department of Horticulture, 206 Tyson Building,
The Pennsylvania State University, University Park, PA 16802

Riddle, James A. and Joyce E. Ford. 2003. ***Organic Vegetable Operation Record Keeping Systems.*** Carolina Farm Stewardship Association.
Online at: ces.ncsu.edu/chatham/ag/SustAg/Vegrecords.doc

Coleman, Eliot. 2009. ***The Winter Harvest Handbook***. Chelsea Green Publishing Company. White River Junction, VT.

Publications from Iowa State University Extension Online Store

https://www.extension.iastate.edu/store.
(Most are available online to download as pdf files)

Midwest Vegetable Production Guide for Commercial Growers 2009.
Cost: $7.50. Online at: extension.iastate.edu/store/ItemDetail.aspx?ProductID=1774&SeriesCode=&CategoryID=55&Keyword=

Chase, Craig. 2006. ***Iowa Vegetable Production Budgets***. PM2017. Iowa State University Extension. Cost: $2.25. Online at: extension.iastate.edu/store/ItemDetail.aspx?ProductID=12219&SeriesCode=&CategoryID=55&Keyword=

Ellis, Jason, Dan Henroid, Catherine Strohbehn and Lester Wilson. 2004.***On-farm Food Safety: Guide to Good Agricultural Practices (GAPs)***. PM1974A. Iowa State University Extension. Online at: extension.iastate.edu/store/ItemDetail.aspxProductID=6540&SeriesCode=&CategoryID=44&Keyword=

Strohbehn, Catherine, Jason Ellis, Dan Henroid and Lester Wilson. 2004. ***On-farm Food Safety: Guide to Food Handling***. PM1974B. Iowa State University Extension.
Online at: extension.iastate.edu/store/ItemDetail.aspx?ProductID=6540&SeriesCode=&CategoryID=44&Keyword=

Henroid, Dan, Catherine Strohbehn, Jason Ellis and Aubrey Mendonca. 2004. ***On-farm Food Safety: Guide to Cleaning and Sanitizing.*** PM 1974C. Iowa State University Extension.
Online at: extension.iastate.edu/store/ItemDetail.aspx?ProductID=6540&SeriesCode=&CategoryID=44&Keyword=

Midwest Plan Service. 2004. ***Production of Vegetables, Strawberries, and Cut Flowers Using Plasticulture.*** Available for order only from ISU Extension Online Store. Cost: $24.

Appendix F

Structure Suppliers[1]

Agra Tech, Inc. (Pittsburg, California)
agra-tech.com/

Harnois Greenhouses
(St. Thomas, Quebec, Canada)
harnois.com

A. M. Leonard (Piqua, Ohio)
amleo.com

Atlas Greenhouse Systems, Inc.
(Alapaha, Georgia)
AtlasGreenhouse.com

Conley's Greenhouse Mfg.
(Montclair, California)
conleys.com

CropKing, Inc. (Seville, Ohio)
www.cropking.com

FarmTek (Growers' Supply) (Dyersville, Iowa)
farmtek.com

GothicArch Greenhouses (Mobile, Alabama)
gothicarchgreenhouses.com

Grow-It Greenhouse
(West Haven, Connecticut)
growitgreenhouses.com

Paul Boers Ltd.
(Vineland Station, Ontario, Canada)
paulboers.com

Plastitech (Saint-Remi, Quebec, Canada)
www.plastitech.com

Poly-Tex Inc. (Castlerock, Minnesota)
poly-tex.com

Haygrove Tunnels
(Elizabethtown, Pennsylvania)
haygrove.co.uk

Hummert International (Earth City, Missouri)
hummert.com

International Greenhouse Company
(Georgetown, Illinois)
igcusa.com

Jaderloon (Irmo, South Carolina)
jaderloon.com

Keeler Glasgow (Hartford, Michigan)
keeler-glasgow.com

Ledgewood Farm
(Moultonboro, New Hampshire)
603-476-8829

Lost Creek Greenhouse Systems
(Mineola, Texas)
hoopbenders.net

Ludy Greenhouses
(New Madison, Ohio)
ludy.com

Quiedan Company
(Salinas, California)
quiedan.com

Rimol Greenhouse Systems
(Hookesett, New Hampshire)
rimol.com

Speedling Inc. (Sun City, Florida)
speedling.com

Tunnel Tech
(LaSalette, Ontario, Canada)
tunneltech.ca

Stuppy Greenhouse Mfg
(Kansas City, Missouri)
stuppy.com

[1]Mention or exclusion of any proprietary product or company does not imply endorsement. Adapted from Hightunnels.org.

Appendix G

Plant Disease Identification Form

IOWA STATE UNIVERSITY
University Extension

Submit samples and form to:

Plant and Insect Diagnostic Clinic
327 Bessey Hall Iowa State
University Ames, IA 50011
515-294-0581

For Office Use Only
Sample No.: ____________
Contact: ______________
Date Received: __________
Mailed: _______________
Entered: ______________
Charge: _______________

Please use a separate form for each plant problem. Include a check or money order (payable to Iowa State University) for $10.00 per sample.

County of owner: ______________________________

Owner: ______________________________________

Address: ____________________________________

____

Phone: ______________________________________

E-mail: ______________________________________

Date: ___________________________________

Submitted by: __ __________________________

Address: _________________________________

____

Phone: ___________________________________

E-mail: __ ________________________________

Please indicate where report should be sent: ❑ Owner or ❑ Submitted by

Plant ID: ______________________________________

See page 2 of form for instructions on collecting and shipping plant samples.

Describe the problem and include details about the site conditions. Photos are helpful.

Circle all that apply:

Symptoms:	**Affected parts:**	**Distribution:**
leaf spot	whole plant	entire field
wilting	leaves/needles	single plant
yellowing	stem	scattered
galls	roots	high areas
root rot	flowers	low areas
marginal burns	fruit	wet areas
leaf/needle drop	bark	dry areas
stunting	other ______	sunny areas
other ________		shaded areas

When was the problem noticed? __________________
How quickly has the problem progressed? __________
____
Are other plant species also affected? ____________
Age/Planting date/Size: _______________________
Watering practices: ___________________________
History of chemicals/fertilizers: _________________
____

Disease diagnosis and control (Do not write in this space):

PD 31 Revised March 2009

Appendix H

Instruction for Taking Soil Samples

Soil tests are only as accurate as the samples submitted for analysis. Therefore, proper collection of soil samples is extremely important. Special bags for submitting soil samples can be obtained free from your Iowa State University Extension County office.

1. Obtain at least one separate composite sample for each acre, or less if conditions vary. For lawns, one composite sample is sufficient, or at most one each from front and back lawn. A composite representative sample consists of up to 15 cores.

2. Obtain a separate composite sample for each different soil type. Difference in soil type can be noted by texture, color, drainage and slope.

3. For each composite sample, use a soil probe, soil auger, spade or garden trowel and obtain a small core of soil from at least 10 to 15 different places in the same area. Place the cores in a clean bucket and mix well. Take about one cup to one and a half cups of the soil and place in sample bag to submit for testing.

4. To obtain the core, scrape away the surface litter. With one of the tools mentioned above, take a small core from the plow layer (0 to 6 inches deep) for vegetables, flowers and fruits, and place in the bucket. In case of row crops, take the cores between the rows.

5. For ornamental trees and shrubs, take the soil cores to a depth of 12 inches.

6. In lawns and other established turfgrass areas, take the cores to a depth of 3 inches below the sod. Do not include the "sod" plug or cap in the sample.

7. Label each sample bag with a number and your name. Number the samples in consecutive order as 1, 2, 3, etc. Keep a record of these numbers.

8. Samples should be sent to the Soil and Plant Analysis Laboratory in a field-moist condition. Do not dry the samples before mailing.

9. Mail the samples to the Soil and Plant Analysis Laboratory within 24 hours after they are taken. If this is impossible, put the samples in the refrigerator or deep freeze until they can be mailed.

10. Be sure to keep a record for yourself of the area from which the samples were taken. This sheet will not be returned to you.

11. Magnesium analysis is only available for vineyards. Interpretation for magnesium will not be made by the lab for any other crops.

12. SMU are soil map units. Use the soil survey map for your county to determine soil types in the areas to be sampled before collecting sample cores. The soil survey for a particular county is available at most ISU Extension County offices.

Appendix I

Produce Farm Case Studies

Case Study 1: Slack Hollow Farm, Argyle, New York

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

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

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

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

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

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

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

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

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

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

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

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

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

From: Blomgren, T., T. Frisch and S. Moore. 2007. High Tunnels: Using Low Cost Technology to Increase Yields, Improve Quality, and Extend the Growing Season. University of Vermont Center for Sustainable Agriculture. www.uvm.edu/sustainableagriculture/hightunnels.html

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

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

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

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

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

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

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

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

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

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

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

From: Blomgren, T., T. Frisch and S. Moore. 2007. High Tunnels: Using Low Cost Technology to Increase Yields, Improve Quality, and Extend the Growing Season. University of Vermont Center for Sustainable Agriculture. www.uvm.edu/sustainableagriculture/hightunnels.html

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

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

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

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

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

Fixed Costs

Construction Costs		**Materials**	**Labor**
Site preparation, bulldozer			$1,000
High tunnel construction			$2,100
High tunnel frame		$5,000	
Lumber and hardware		$500	
Endwall finishing		$400	
Water service			$850
Irrigation		$700	
Bed preparation		$240	
	Subtotals	**$6,840**	**$3,950**
	Total Construction Costs		**$10,790**
Fixed Costs			
High tunnel construction (divided by 15 years)			$719
Interest (construction financed at 7% for 15 years)			$378
Taxes, land, office expenses, fees			$1,377
	Total Fixed Costs		**$2,474**
	Total Fixed Costs (six-month winter season)		**$1,237**

Variable Costs (six-month winter season)

Materials and Machinery			**Cost**
Seeds			$50
Compost			$200
Irrigation supplies			$50
Row Cover			$100
Poly covering (divided by 4 years)			$90
Packaging			$30
Delivery costs			$560
	Subtotal		**$1,080**
Labor Costs			
Bed preparation and fertilization			$500
Seeding			$48
Irrigating			$100
Harvesting, grading, packing			$1,500
Sales and delivery			$1,500
High tunnel clean-up			$100
	Subtotal		**$3,748**
	Total Variable Costs		**$4,828**
		Total Costs	**$6,065**
		Revenues*	**$12,000**
		Net Returns	**$5,935**

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

From: Blomgren, T., T. Frisch, and S. Moore. 2007. High Tunnels: Using Low Cost Technology to Increase Yields, Improve Quality, and Extend the Growing Season. University of Vermont Center for Sustainable Agriculture. www.uvm.edu/sustainableagriculture/hightunnels.html

Appendix I2
Case Study 2: Cedar Meadow Farm, Holtwood, Pennsylvania

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

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

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

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

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

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

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

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

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

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

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

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

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

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From: Blomgren, T., T. Frisch and S. Moore. 2007. High Tunnels: Using Low Cost Technology to Increase Yields, Improve Quality, and Extend the Growing Season. University of Vermont Center for Sustainable Agriculture. www.uvm.edu/sustainableagriculture/hightunnels.html

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

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

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

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

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

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

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

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

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

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