HIGH TUNNEL HANDBOOK

B-1234
June 2013

UNIVERSITY OF WYOMING
EXTENSION

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Issued in furtherance of extension work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Glen Whipple, director, University of Wyoming Extension, University of Wyoming, Laramie, Wyoming 82071.

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1 THOUGHTS from a commercial grower

Scott Richard, Shoshone River Farm, Cody, Wyoming

I have used cold frames for the past 20 years with some success, but was always somewhat disappointed with the results, expecting more return for the effort. I always looked for better designs and in my search I found the "high tunnel" or "hoop house". Information on these structures promised up to six weeks earlier production in the spring and the same six weeks after the first frost in the fall. An extra 12 weeks would nearly double my growing season in Northern Wyoming. The structures were simple plastic-covered buildings of different sizes, shapes, and large enough to walk and work within. Pictures and videos showing people from Alaska to Jamaica growing crops in them were very encouraging. I built my first in the summer of 2008 with PVC pipe and lumber that I had around the yard.

That first year I harvested lettuce in early April and bell pepper plants 4 feet tall in summer from the high tunnel. Since then, harvests in the tunnels have been consistently weeks earlier and better quality than those harvested outside.

The tunnels increase my growing season from 50-100 days, depending on the year, to at least 180 days (six months). Managed correctly, two short-season crops per year can easily be harvested from the tunnels. I have harvested tomatoes from June through mid November. I have planted salad greens early and followed them with determinate (bush) tomatoes and herbs in July. With reasonable fall temperatures, tomato harvests in the tunnels continue through September. Options for growth are limited only by the number of square feet covered.

This will be my fourth year commercially growing in high tunnels. In my experience, internal row covers provide enough additional cold protection in the spring. When outside temps dropped below 28 degrees F in the fall, I have allowed the tunnels to freeze. I have used portable heaters to encourage earlier/later production of tomatoes and peppers. The input of heat can significantly increase operating costs.

Summer temperatures outside dramatically increase inside temperatures, often requiring venting of the tunnels. Summer nighttime temperatures often drop quickly below 50 degrees F here in Northern Wyoming. The tunnels help slow this cooling and often provide 5 or more degrees difference. Summer days, windless and hot, and mild overnight temperatures ripen a tomato or pepper. Each variety of plant requires a number of "degree days" till harvest. The "degree day," the difference between average temperature and the base temperature [{Tmax + Tmin)]/2 needed for growth of the crop, is a measure of the growth rate of the plant. This number has to be met to ripen a tomato in the "days to harvest" that is noted on seed packets. Here in Cody, Wyoming we often don't get warm enough days and nights to ripen warm season vegetables. The warmer high tunnel/hoop house temperatures encourage tomatoes, peppers, cucumbers and other warm-loving vegetables to form earlier, larger and better quality crops. Too much heat, however, reduces harvests and can sterilize the environment.

Temperature fluctuations are the most time consuming problem I have with tunnels. Tunnels without automatic vents have to be monitored regularly throughout the day and growing season for temperature. I have damaged crops when tunnels overheated. This usually happens when a spring snow ends in the late morning and the sun comes out. If you aren't there to open doors, internal temperatures will increase quickly to killing temperatures. Cold temperatures can be equally damaging. Doors must be closed as temperatures begin to fall to hold in warmer air. The use of automatic vents is recommended. Several may be required for small tunnels. Without these vents, someone must be around to open and close doors or windows.

The warm high tunnel/hoop house environment allows aphids and spider mites to grow faster, causing more damage in a shorter time. The damp, warm, windless tunnel encourages fungi such as powdery mildew to develop. Tunnels are also ideal places for mice to proliferate, destroy crops and, potentially, spread disease. The use of chemicals must be done with great caution. Closely follow all safety procedures and use appropriate protective clothing. I do not use petrochemical pesticides and find organic pest management to be adequate.

I planted salad greens in early September and am still harvesting early in December. These greens have frozen solid more than five times, and have seen below zero temperatures. As the tunnel warms on sunny days, the frost comes out of the greens. Once it looks like lettuce again, I harvest. Shelf life is reduced to around five days as compared to summer lettuce of 10-14 days.

Growing vegetables isn't easy. This technology only provides a warmer growing environment. I have struggled at times to learn how to manage tunnels and associated problems. I can't say they have made my life easier. In fact, they have required additional work to get earlier and later crops. I find myself planting seeds from April through August and harvesting through November. I enjoy growing vegetables and working garden soil in February when it's cold outside. These hoop houses are the best cold frames I have ever used and deliver more vegetables of better quality. Adding heat and row covers will provide additional increases in the growing season. I hope this book will encourage you to try this technology.

Figure 1.1. Three styles of high tunnels: straight hoop, hard sided, and gothic at the Powell Research and Extension Center. (Photo: Sandra Frost)

2 High Tunnels
ECONOMICS and MARKETING

Does it make economic sense to build a high tunnel and grow my own food or produce food for others?

Jeff M. Edwards

As with any endeavor there will be initial setup costs. Here is a partial list of items that you may need to consider as expenses when setting up your growing space:

Table 2.1 Items needed for high tunnel production.

Land Rental	Water	Storage Space & Shelving
Tillage Tools	Fertilizer	Refrigeration
Planting Tools	Plant Supports	Packaging Containers
Watering Tools	Pest Management Strategies	Shipping Containers
Seeds	Harvest Tools	Fuel & Maintenance
Plant Starts	Harvest Containers	Hired Help
	Sanitation	Value of Time

In addition to this list of items, the initial cost for the structure can be quite high depending on the design and source materials you choose for your high tunnel. UW Extension has been conducting educational workshops around Wyoming to teach participants how to build their own high tunnels from locally available materials (excluding the woven poly "skin"). These designs are a much less expensive option than purchasing a kit – and can more easily be modified to fit into a back yard or a tight budget. The designs used have been adopted and modified for Wyoming conditions from structures created by Del Jimenez at New Mexico State University.

The cost for one of these modified NMSU structures is dependent upon the design and local sources, but on average during 2010 and 2011 the purchase price of materials from local lumber yards in Wyoming could be broken down as follows:

Table 2.2 High tunnel material costs.

High Tunnel Description	Dimensions (foot print)	Inside Growing Area (Square feet)	Approximate Materials Cost	Cost per square foot of inside growing area
Straight Hoop	12' X 12'	144	$ 450.00	$ 3.13
Straight Hoop	12' X 32'	384	$ 1200.00	$ 3.13
Hard Sided High Tunnel	16' X 32'	512	$ 1600.00	$ 3.13
Gothic Style*	17' X 32'	544	$ 1400.00	$ 2.57

*Although a less expensive option, the gothic style is not recommended for areas of Wyoming where significant snow accumulation can occur as the structure does not shed snow easily and may collapse under snow load.

Expenses are only a part of the equation (expenses). Potential return can be better understood by taking a look at the production per unit space in a high tunnel, calculating the potential yield for a crop in the entire space and multiplying by the expected market value of the total amount of the crop expected to be produced.

The crop production table below (Rabin, J., G. Zinati, and P. Nitzsche. 2012. Yield expectations for mixed stand, small-scale agriculture. New Jersey Agricultural Experiment Station. September 2012, Volume 7, Issue 1. 4p. Modified by Edwards, J.M. to include marketing data.) has been modified to include the USDA Current Sale Market Value (CSMV) for a specific time period.

Table 2.3 Yield and estimated market value of selected vegetable and small fruit crops when grown in a high tunnel. Value is based on the estimated production for the single crop being grown in the high tunnel.

	Avg. Yield/ft2	Estimated Total Yield/ High Tunnel	USDA Current Sale Market Value (Week of 12/05/2011)	Estimated Crop Value
	(no. or lbs.)	(no. or lbs.)		
Beans (bush)	0.5 lbs	150 Lbs	$ 1.41	$ 211.50
Broccoli	0.4 lbs	120 bunches	$ 1.82	$ 218.40
Cantaloupes	1.5 lbs	450 Lbs	$ 0.75	$ 337.50
Carrots	16 carrots	4800 bunches	$ 0.33	$ 1,584.00
Cucumbers (slicing)	3.5 lbs	1050 Lbs	$ 0.74	$ 777.00
Kale (full size)	3 bunches	900 bunches	$ 0.99	$ 891.00
Lettuce (baby salad)	0.5 lbs	150 Lbs	$ 0.96	$ 144.00
Lettuce (head)	1.2 lbs	360 Lbs	$ 0.90	$ 324.00
Onions	0.6 lbs	180 Lbs	$ 0.64	$ 115.20
Potato (Irish)	1.5 lbs	450 Lbs	$ 0.78	$ 351.00
Raspberries (primocane)	0.4 lbs	120 Lbs	$ 6.72	$ 806.40
Spinach (Full size)	0.5 lbs	150 Lbs	$ 2.67	$ 400.50
Strawberries (June-bearer)	0.8 lbs	240 Lbs	$ 3.62	$ 868.80
Squash (Summer) Early	1.3 lbs	390 Lbs	$ 1.22	$ 475.80
Squash (Summer) Full-season	4.5 lbs	1350 Lbs	$ 0.82	$ 1,107.00
Tomato (slicers)	1.8 lbs	540 Lbs	$ 1.34	$ 723.60
Tomatoes (salad)	1.2 lbs	360 Lbs	$ 2.18	$ 784.80
Peppers (bell)	2 lbs	600 Lbs	$ 1.49	$ 894.00

Estimated total yield based on 300-sq ft (78%) bed space per 12-ft X 32-ft high tunnel.

These values are generated weekly by the USDA as a survey of the sale advertisements for particular specialty crop commodities across the United States. This report is available at: http://www.ams.usda.gov/mnreports/fvwretail.pdf.

As with any marketing document these values will change, but it is an excellent reference to find the appropriate price point for your product if it is being sold on the open market or at a local Farmers Market. Do your homework and know the full cost of all inputs before negotiating the price on a commodity you are going to sell.

These values represent the estimated gross income for a single crop. Add this to a multiple cropping strategy, plus the extended growing season in a high tunnel and you can see how the relatively small space of a high tunnel can be very productive. With a little creativity, a successful growing season and an effective marketing strategy for your products, you should be able to capture much of your initial expenses within the first growing season.

Figure 2.1. Delicious harvest.

3

ENVIRONMENT MANAGEMENT

Sandra Frost

High tunnels are designed to extend the growing season by providing crop conditions for a longer time using simple and inexpensive technology. High tunnels use solar energy to heat air and soil inside the tunnels (passive solar energy).

Just as a grower routinely checks soil fertility, so he/she should also check conditions inside the high tunnel to ensure plants grow in optimal conditions. Monitoring air and soil temperature, soil moisture, relative humidity, and light is important for production of any crop. An investment in data loggers and computer software that will download and store data and graph trends will facilitate keeping a record of conditions in the high tunnel throughout the year. A list of data logger manufacturers is available at http://www.microdaq.com/data-logger/index.php.

Some of the variables that should be monitored in a high tunnel are:

Air Temperature

Temperature regulates how fast photosynthesis, the formation of sugars from carbon dioxide, and every other chemical reaction in plants takes place. The warmer it is, the faster chemical reactions take place. It can, however, become too warm for the crop to survive. Each plant species has a temperature range it prefers for growth. Critical air temperatures include the minimum temperature at which growth starts, the optimum temperature for efficient growth, and the maximum air temperature at which growth ceases (Table 1).

Air temperatures in high tunnels can fluctuate greatly over several hours. A grower will have to open and close doors and vents, depending upon what crop is grown. Solar powered fans or vents mounted above doors can also move air through a high tunnel. This can be labor intensive during spring and fall when there is a large difference between day and night outside temperatures and the sun angle is changing. High tunnel doors and vents may be left open all summer in Wyoming once external air temperatures have stabilized. Current practice in Wyoming is to leave the high tunnel cover on through summer.

Table 3.1 Critical air temperatures for some common vegetables.*

Crop	Temperature (F)		
	Min	**Optimum**	**Max**
Hot Pepper, Eggplant, Okra	65	70-85	95
Cucumber	60	65-75	90
Onion, Garlic	45	55-75	85
Snap Bean, Lima Bean	50	60-70	80
Tomato, Sweet Pepper	65	70-75	80
Beet, Broccoli, Cab-bage, Chard, Radish	40	60-65	75
Carrots, Lettuce, Peas, Potatoes	45	60-65	75

* Maynard, D.N. and G.J. Hochmuth. 2007. Knott's handbook for vegetable growers. 5th edition. Wiley & Sons, Inc.

There are several ways to cool a high tunnel. Open doors and/or side vents to cool a high tunnel. Install a temperature regulated, solar powered vent or fan over each door. Apply shade cloth over top of the covering, with the vents open, to provide protection for cool season crops.

Figure 3.1. Interior of gothic high tunnel style in summer with vents open. (Photo: Sandra Frost)

Growers may also remove the covering for the summer if it can be done easily.

Close doors and vents to hold heat in the high tunnel. Use row covers or low tunnels over crops to hold heat during the coldest parts of winter. Both trap heat released by soil and hold it near plants. Some producers build compost pits inside high tunnels. Compost releases heat as it decays. Select crops that match conditions in the high tunnel.

Soil Temperature

Soil temperature changes more slowly and varies less than air temperature. However, the temperature of the top 2 inches of soil does fluctuate and highly influences seed germination. Seeds of different crops require different soil temperatures for germination (Table 3.2). Place a soil thermometer at seeding depth to check soil temperature. Soil in a high tunnel is a heat sink in fall, i.e. it holds heat into winter. Soil will re-radiate that heat to the high tunnel and warm the interior air. Black plastic mulch laid over soil will increase soil temperature.

Light

Light transmission through covering materials varies by manufacturer from approximately 55% to 92% transmission. Select the highest transmission material you can afford. The location of high tunnels can impact access to light. For example, trees too close to high tunnels can cast shadows that cut down plant production. High tunnels too close to each other can cast shadows as well. Plant spacing also impacts the amount of light hitting leaves of each plant. Do not allow one plant to shade another when full grown. Plant tall crops on the north side of a high tunnel so they will not shade other crops. If you want to cool the high tunnel in summer, the amount of light in a high tunnel can be reduced with shade cloth over the top.

Table 3.2 Soil temperature requirements for seed germination.*

Crop	Min Temp (F)	Max Temp (F)	Optimum Temp Range (F)
Asparagus	50	95	60-85
Bean	60	95	60-85
Bean, lima	60	85	65-85
Beet	40	95	50-85
Cabbage	40	100	45-95
Cantaloupe	40	100	75-95
Carrot	40	95	45-85
Cauliflower	40	100	45-85
Celery	40	85	60-70
Chard, Swiss	40	95	50-85
Corn	50	105	60-95
Cucumber	60	105	60-95
Eggplant	60	95	75-90
Lettuce	35	85	40-80
Okra	60	105	70-95
Onion	35	95	50-95
Parsley	40	90	50-85
Parsnip	35	85	50-70
Pea	40	85	40-75
Pepper	60	95	65-95
Pumpkin	60	100	70-90
Radish	40	95	45-90
Spinach	35	85	45-75
Squash	60	100	70-95
Tomato	50	95	60-85
Turnip	40	105	60-105
Watermelon	60	105	70-95

* Maynard, D.N. and G.J. Hochmuth. 2007. Knott's handbook for vegetable growers. 5th edition. Wiley & Sons, Inc.

Relative humidity

Relative humidity is the ratio of the amount of water vapor actually present in the air to the greatest amount possible at the same temperature (Merriam-Webster Dictionary). High tunnels that are not vented well or are over irrigated provide a warm humid environment perfect for diseases. High relative humidity also contributes to interior condensation on walls that drips onto plants. Wet leaf surfaces are vulnerable to fungal and bacterial diseases. There may be times when it is too cold to vent. You may be able to use row covers or low tunnels to prevent water dripping onto leaves. Some high tunnel coverings are treated with additives to inhibit condensation. Combine good ventilation with appropriate irrigation to hold humidity at a low level.

Water

Locate the high tunnel near a year-round, high quality water source. Water quality data for municipal water sources is often available from your city or town. If you are using well water, have it tested for irrigation suitability periodically. Install pipes below frost depth. Water should drain away from the high tunnel foundation. See the chapter on irrigation.

Soil moisture

Build up soil moisture through the entire crop rooting system before planting seeds. This will provide a uniform moist environment for seed germination and emergence. Maintaining uniform moisture in the root zone is critical to ensure high yields and crop quality. Soil moisture probes that monitor moisture levels can be inserted between plants. Crops have varying water demands depending upon growth stage. It is important to meet those demands in a timely fashion. See the chapter on irrigation.

Conclusion

High tunnel environments are variable on a daily, monthly, annual scale. Selecting a high light transmission cover material, planting seeds at the right soil temperature, and maintaining optimum air temperature and soil moisture will provide your crops with conditions to extend Wyoming's growing season.

Figure 3.2. Plants such as pumpkins, cucumbers, and squash can be irrigated using drip irrigation, as can a number of high tunnel crops. (Photo: Sandra Frost)

4 PLANTING BED LAYOUT

Sandra Frost

Grower's goals for a planting bed layout may include: intense management, high production, high quality crops, and convenience. Beds may be in the native soil, in soil slightly elevated by tillage, or in fabricated raised beds made of wood or plastic.

Planting bed orientation

Beds can be oriented lengthwise in the tunnel and separated by walkways. This design is especially good for trellised vegetables or fruit that will benefit from unobstructed air circulation through doors or vents in gable ends. Low tunnel row covers can easily be put on or removed from the long rows. Drip irrigation requires few connections. Further, long rows are suitable for vertical growing techniques. In addition, long beds in native soil are more easily worked and roto-tilled.

Planting beds may also be perpendicular to the length of the tunnel with a central walkway from end to end. Planting and harvest can be done with short travel distances. A central path makes it easy to bring in materials and take out harvest. An overhead cable platform could be installed for moving materials. There are two challenges with this design. The end of the bed close to the exterior wall of the tunnel will be cooler than the end in the center of the tunnel. Cooler temperatures may result in slower, reduced growth. The exterior sides of a hoop style tunnel are difficult to access because of the short height. Beds are more accessible in a straight sided high tunnel than in a hoop shaped tunnel.

A third configuration is lateral beds across the entire tunnel with paths longitudinally along the exterior walls. Whether this design works depends upon the design of the high tunnel. Short side walls will make this configuration difficult to work in.

Figure 4.1. Proper plant spacing is key for healthy yields. (Photo: Jeff M. Edwards)

Row Spacing

Proper row spacing promotes air circulation among plants and decreases relative humidity. A dry environment near plant leaves decreases the risk of infection by fungal or bacterial diseases. The mature leaf canopy size determines the row and seed spacing, not the size of the seed. Follow your seed supplier's recommendations.

Row spacing and irrigation are intimately linked. Make sure roots of plants in each row will receive water all season long.

Crops such as beans and peas may be planted in 2 rows with a trellis in the center for support. Small seeded crops such as carrot and lettuce can be sowed thickly in a row and thinned later. Pre-measured seed tapes are available for many varieties of small seeded crops. You may also want to make your own seed tapes.

Staggered planting patterns like that used in square foot gardening also work well in high tunnels. Place plants on alternate sides of drip irrigation lines.

Lettuce and baby greens can be planted in rows relatively close together – just 3 inches apart (6 to 9 rows in an 18 inch bed). In contrast, consider the season-long size of crops such as squash, tomato, cucumber and peas. Allow room for the mature plants to have enough light and ventilation. In particular, plan for the luxuriant growth of indeterminate vining tomato varieties. You may have to defend the walkways or grow the plants vertically as the season progresses.

There are several different trellis systems in use for tomatoes and cucumbers. Vertical support posts six feet tall are set every 5 to 10 feet and connected by 12-guage wire. Twine is tied to the wire and fastened to the ground. Plants can be clipped to the twine. Some growers use double armed T-posts with wire strung between the arms to support berries or vegetables. A lower support called "Florida weave" may be used for determinate tomatoes. Do NOT fasten wire from one end gable to the other. The weight of crops will pull the ends in toward the center and the high tunnel will collapse.

Research on row spacing

Recommendations from Utah State University high tunnel research:

Tomatoes

- planted 18 to 24 inches apart in rows 36 to 48 inches apart
- Determinate – staking, Florida weave
- Indeterminate – trellising, Florida weave, overhead wire & twine,

Raspberries

- planted every 2 to 3 feet within the row and about 6 feet between rows
- High tunnel design should have vertical side walls of 5 to 6 feet

Strawberries

- annual hill system – planted 12-15 in apart in row, staggered rows 12-15 inches apart, Runners removed.
- beds usually are 2-4 rows wide. Each row is 1 ft wide therefore,
- a 4-row bed is 4 ft wide

Lettuce

- can be direct seeded or transplanted into high tunnel
- Baby leaf lettuce – rows 2-3 in apart (6-9 rows on an 18 in bed)
- In-row spacing 1 inch or more
- Transplant Lettuce – 4-6 in apart (4-9 plants/ sq ft)
- in 2-3 foot wide beds

For more Utah State University research results visit the high tunnel website at www.tunnel.usu.edu.

5

SOIL MANAGEMENT

Kelli Belden and Sandra Frost

Introduction

Soils in high tunnels are highly managed and will be used and cultivated throughout the year. Soil temperatures will often be elevated as will soil moisture. These conditions will favor insect and microbial action, plant growth, and rapid organic matter decay. Additions of organic matter will be necessary to maintain soil fertility and soil volume. Periodic, routine soil monitoring will be the key to success in high tunnel production.

No matter what soil a producer starts with or what philosophy a producer uses, he/she will want to:

- Build soil organic matter to approximately 5% without creating high nutrient levels
- Protect soil structure
- Rotate crops to prevent development of soil born plant pathogens
- Maintain soil moisture
- Maintain good sanitation by disposing of residues from within the tunnel elsewhere to avoid concentration and dispersal of insect, weed, and disease problems

The decision to manage the soil in your tunnel organically or with a combination of natural and conventional practices should be made before your site is selected. You may be able to start high tunnel construction on a site that is already certified organic. Otherwise, you may have to work through the three year transition to organic, or you may want to use conventional production methods. Consult the organic chapter if you intend to become a USDA certified organic producer. Proper soil improvement will increase your chances for success in any case.

Soil characteristics in site selection

The geology underlying Wyoming varies widely across the state. Soil characteristics can vary significantly within a short distance due to a change in underlying geology. Here are some guidelines that may help when selecting a site for a high tunnel.

High tunnels should be built on level ground. The high tunnel soil may be elevated above surrounding soil to allow drainage after irrigation. The goal is to have high tunnel soil that is neither too wet, which would foster diseases, or too dry, which would affect nutrient availability.

There are particular soil quality goals that will promote plant growth. Take one or more samples of the soil that will be in the high tunnel and have it analyzed for pH, EC, organic matter, texture, nitrogen, phosphorous, potassium, salts, iron and zinc. Have complete tests done when you select the high tunnel site and redone just before planting because nutrient levels change over time.

Texture is a term used to describe the amount of sand, silt and clay in a soil. Soil textures can be divided into three broad groups: light (sand, loamy sand, and sandy loam) medium (loam, silt loam, silt, and sandy clay loam) and heavy (clay loam, silty clay loam, sandy clay, silty clay, and clay). Light soils drain quickly and need to be watered frequently in order to maintain enough available water for good plant growth. Light soils allow soluble nutrients like nitrate and sulfate to be leached quickly. You may want to split the application of nitrogen to light soils into two or three small applications spaced over the growing season to avoid leaching valuable fertilizer below the crop's root zone.

Figure 5.1. Healthy soil is the best basis for crop health.

A soil test provides accurate information about the condition of soil. Perform a soil test at least every fall on representative samples from different management areas or different soil types. Send samples to a regional laboratory that uses tests appropriate for your area. Make sure the laboratory will test for pH, EC, organic matter, texture, nitrogen, phosphorous, potassium, salts, iron and zinc. Nutrient removal in high tunnels is intense. Trace minerals are also important. Test for copper, manganese, nickel, molybdenum, sulfur, or boron as these may be deficient. In Wyoming soils amounts of calcium and magnesium are not problems, but their availability to plants can be a problem due to poor water management.

Keep a logbook of soil tests for each high tunnel that includes dates, test results, nutrients added, crop rotation history, and production levels.

One land grant university soil lab is the Soil, Plant, Water Testing laboratory at Colorado State University, www.soiltestinglab.colostate.edu

Plant Nutrients

There are currently 17 nutrients that have been shown to be essential for good plant growth. Three of these, carbon (C), hydrogen (H), and oxygen (O) are supplied by air (CO_2 and O_2) and water (H_2O). The others are usually supplied by the soil from organic and inorganic materials. Applying nutrients at the beginning of the season or in small increments during the season, based on a soil test, will help insure that you have no yield or quality losses in your crop due to nutrient deficiency. If visual nutrient deficiency symptoms appear, you have already lost yield and quality. Applying fertilizer after deficiency symptoms appear may save the plant, but you will usually not regain your full yield potential.

The primary nutrients needed by plants are nitrogen (N), phosphorous (P) and potassium (K). The Three nutrients will always be listed on the label of a fertilizer bag. They are always presented in N-P-K order on the bag and expressed as a percentage of the nutrient. For example, a 16-16-16 fertilizer would contain 16% N, 16% P_2O_5 and 16% K_2O. Nitrogen is first and is expressed as the percent pure N, while phosphorous and potassium are expressed as though they were oxides ($P_2O_{5,}$ diphosphorous pentoxide and K_2O, potassium oxide) of the elements. To convert P_2O_5 toP, multiply P_2O_5 by 0.4364 (ex. 10 lb P_2O_5 x 0.4364 = 4.364 lb P). To convert K_2O to K, multiply K_2O by 0.8301 (ex. 10 lb K_2O x 0.8301 = 8.301 lb K).

Nitrogen is most frequently required because many of its forms are easily lost by leaching or volatilization into the air. Although the air contains 78% nitrogen (N2), the gaseous form of nitrogen is unavailable to plants. Legumes (peas and beans), if supplied with the appropriate microorganism (a *Rhizobium* bacteria), can obtain nitrogen from the air and convert it to a form available to plants. If there is a good organic matter reserve in the soil, sufficient nitrogen can be sometimes supplied by its gradual decay. Nitrogen deficiency results in a gradual lightening (called chlorosis) of the green color in leaves. Older leaves generally exhibit these symptoms first. With time, the leaves may eventually go yellow, white, or brown and die. Leaves may be smaller and flowering can be delayed by a lack of nitrogen. Nitrogen in excess can result in dark green vegetation, lodging, delayed maturity of fruits, watery potatoes, and sensitivity to frost damage. The excess may also end up contaminating the ground water if leaching occurs. Very high concentrations of nitrogen can kill your plants.

Inorganic phosphorous (P) is relatively immobile in the soil and is, normally, the second most limiting nutrient. Some organic forms of P are mobile in the soil. Phosphorous deficiency symptoms vary by crop. Sometimes older leaves will appear to be a darker green and the veins take on a purplish color. In corn the older leaves develop a reddish purple cast on the outer border of the leaf.

Most Wyoming soils are high in potassium and need little or no additional potassium to be productive. Potassium deficiency can result in burning of the leaf margins, necrotic spotting, poor quality fruit, and lodging.

Secondary nutrients are calcium (Ca), magnesium (Mg) and sulfur (S). Wyoming soils usually contain sufficient quantities of these nutrients. We sometimes see calcium deficiency symptoms (blossom end rot on tomatoes or other fruits), but these are almost always due to poor water management. It is important to maintain good water availability during flowering and fruiting to prevent calcium deficiency.

The micro nutrients that need regular monitoring in Wyoming are iron (Fe) and zinc (Zn). Iron deficiency is expressed as inter-veinal chlorosis on younger leaves. Many iron fertilizers have limited availability when added to Wyoming soils. It is often more effective to use a foliar application if symptoms occur. Do not apply a foliar product if temperatures will be above 90 degrees F within 24 hours of application. High temperatures will cause leaf damage. Zinc deficiency can result in inter-veinal chlorosis, usually on younger leaves first. High phosphorous levels, which can result from excessive use of manures, can induce a zinc deficiency in soils where zinc concentration is marginal. Adequate zinc will promote crop maturity.

Because of the high level of nutrient removal usually associated with high tunnel production, a deficiency of the other micro nutrients (manganese, copper, boron, chlorine, molybdenum and nickel) may occur. Your best preventive measure is to maintain good organic matter levels, conduct regular soil tests, and assess nutrient deficiencies by a plant tissue analysis.

Medium textured soils are usually the most favorable for plant growth. They generally hold the most plant-available water of the three textural groups, and usually have adequate nutrient-holding capacity.

Heavy soils are often characterized by slow water-infiltration rates, and high potential nutrient-holding capacity. They hold more water than light or medium soils but generally do not release as much of it to the plants as a medium soil. Heavy soils may require more phosphorus than light soils, but are less prone to nutrient leaching losses and require less frequent irrigation than lighter soils. Very light and very heavy soils usually create management problems for the grower. Soil texture is not easily modified and problems with soil texture are usually handled by careful water management and building up soil organic matter.

The pH is a measure of the acidity or alkalinity of a soil. A pH above 7.0 is alkaline while a pH below 7.0 is acidic. The pH of most Wyoming soils is between 7.0 and 8.5. The optimum pH for most crops will fall between about 6.0 and 7.0 (slightly acid), but many plants will actually tolerate a wide range in soil pH.

Perhaps the most common problem observed with pH extremes is nutritional imbalance. Most Wyoming soils have a pH over 7. However, there are acidic soils in a few locations. Very acidic soils can be improved by liming, but alkaline soils resulting from high lime are not easily changed. A very high pH (one over 8.5) may indicate the presence of sodium in your soil and a sodium adsorption ratio (SAR) should be run to determine the sodium status of the soil. Soils high in sodium often have undesirable physical properties such as slow permeability and poor aeration. Normally you would like your SAR to be less than 3. Sodium-affected soils are not easily reclaimed, but may benefit from organic matter and gypsum addition. Consult your UW extension educator if sodium problems are suspected. You will need to request additional tests to determine how to deal with a sodium problem.

Table 5.1. Relative salt tolerance of horticultural crops.*

Woody fruits and trees	Ornamentals, grasses, and groundcovers	Herbaceous fruits, vegetables, and flowers	Interpretation Low	Interpretation Moderate	Interpretation High
			mmhos/cm		
		Sensitive			
Apple	American linden	African violet	0-2.0	2.1-4.0	>4.0
Cherry & Prunus *spp.*	Cotoneaster	Bean			
Chokecherry	Little leaf linden	Carrot			
Currant	Mock orange	Onion			
Gooseberry	Oregon grape	Parsnip			
Pear	Redtwig dogwood	Strawberry			
Plum	Rose				
Raspberry					
		Moderately Sensitive			
Aspen	Clematis	Broccoli	0-3.0	3.1-6.0	>6.0
Black locust	Common snowball	Cabbage			
Cottonwood	English ivy	Cantaloupe			
Fir	Honeysuckle	Corn			
Grape	Kentucky bluegrass	Cucumber			
Green ash	Lilac	Flowers, general			
Honey locust	Orchardgrass	Gladiolus			
Maples (most)	Privet	Lettuce			
Poplar	Service berry	Pea			
Siberian elm	Wayfaring tree	Pepper			
Spruce	Yellow sage	Potato			
Willow		Pumpkin			
		Radish			
		Spinach			
		Tomato			
		Turnip			
		Watermelon			
		Moderately tolerant			
Autumn olive	Blue grama	Beet	0-6.0	6.1-12.0	>12.0
Evergreens, general	Buffalo grass	Carnation			
Hackberry	Caragana	Chrysanthemum			
Juniper	Crested wheatgrass	Squash, zucchini			
Pine	Fine fescue				
	Perennial ryegrass				
	Potentilla				
	Tall fescue				
		Tolerant			
	Alkali grass	Asparagus	0-9.0	9.1-15.0	>15.0
	Creeping bentgrass				
	Iceplant				

**This list is only an indication of the salt tolerances of major plant groups. These "indicator" plants can be useful in determining the salt tolerances of closely related plants or plants adapted to similar sites.*

Salt buildup, or soil salinity, is common in arid and semi-arid regions and is a significant problem in Wyoming soils. The soil may be naturally salty or the salinity may be caused by poor-quality irrigation water, poor irrigation management and/or poor soil drainage. Soil salinity may usually be corrected by improving soil drainage and leaching. A plant's sensitivity to salts can vary with plant growth stage. Many species are more sensitive to salts during germination and emergence than during vegetative growth. Contact your UW extension educator for specific crop salinity tolerances. In general, if the salt estimate is less than 2.0 dS/m, salt should not be a significant problem.Organic matter is an important factor in maintaining the soil's desirable chemical and physical properties. Organic matter improves water-holding capacity (especially plant-available water), permeability, aeration, and resistance to compaction. Organic matter increases the soil's ability to absorb and hold plant nutrients, and will release nutrients as it decomposes. Many Wyoming soils contain less than 2 % organic matter and will benefit from practices that encourage organic matter accumulation.

In addition to taking a soil sample for a laboratory test, dig a hole at least twelve inches deep on the site and check for worms and compaction. The presence of worms usually indicates that you have a healthy soil. A compacted soil will have few air spaces because the soil particles are packed together very tightly. Compaction makes it difficult for water to drain freely.

Digital maps of Wyoming native soils and general soils data are available from the Natural Resources and Conservation Service (NRCS) for your county http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm .

Your county UW Extension Educator can help you interpret maps and soil analyses and take soil samples. http://www.uwyo.edu/ces/

Soil Fertility Management

Your goal may be to manage high tunnel soil to promote high quality crops with high yields across a diversity of crops. Each crop uses varying types and amount of nutrients from the soil. Crops may be planted directly into native soil, into raised beds, or into containers of soil.

Organic matter

The addition of organic matter improves soil texture by increasing water holding capacity and by providing pore space for roots to grow. Organic matter also holds nutrients in the soil that might leached with water. Use organic matter to modify drainage, improve water retention or reduce soil texture/structure problems. Add fresh, out-sourced, high quality organic matter when needed. Avoid over use of composted manure which can lead to high levels of P above the optimum. Do not attempt to modify soil texture by adding sand or clay. Wyoming soil chemistry will often create a mortar-like material which sets up like concrete.

Select well aged manure and composted manure carefully because both can be a source of pathogen contaminants and salts. A laboratory can test your manure to be sure the salt level is acceptable. The potential presence of pathogens is more difficult to deal with properly. Use of manure on plants intended intended for human consumption can be risky. Never use dog, cat or pig manures on plants you plan to eat. They often contain parasites that can infect humans. The parasites can survive a long time in the soil. Don't even add them to your compost pile. All manures may contain pathogenic strains of *Salmonella sp.* and *E. coli* bacteria. As the manure ages the bacteria decline but they can still be a potential threat to your health. The USDA Organic Standard (http://www.ams.usda.gov/AMSv1.0/nop) requires that after application of aged uncomposted manure, you must wait 90-120 days depending on the crop grown before harvesting crops for human consumption. The 120 day wait applies to anything grown in a vegetable garden. The 90 day wait would apply to fruit trees. You can compost manure to minimize the risk of pathogenic organisms, but it is hard to maintain the appropriate conditions throughout the compost pile. The USDA Organic Standard requires that, the compost pile must be maintained at 131 F to 170 F for 3 days using an in-vessel or static aerated pile. Manure should always be avoided if anyone whose immune system is likely to be weak (including infants and the elderly) is likely to eat produce from the garden. Remember the use of manure is even a risk to healthy human beings. Other sources of organic matter may include: sawdust, green manure from a cover crop, leaves, straw, peat moss, and even shredded newspaper printed with vegetable inks.

Tillage Practices

Soil structure is affected by how much the soil is disturbed. The goal is to have nutrients, air and water available throughout the plant rooting depth. Roto-tilling will completely turn over the soil and incorporate any amendments. Hand forking a bed will loosen soil without turning it over and allow some incorporation of amendments. Layering amendments on the surface and lightly incorporating them down to 2 inches disturbs soil structure the least.

Fertilizers

Nutrients can be supplied by organic or inorganic, manufactured fertilizers. Each form has advantages and disadvantages. Crop plants take up nutrients in the inorganic from, so the nutrient supply from organic materials depends on the rate of decomposition of the organic forms. Organic materials usually degrade more completely during a season of growth in a high tunnel than they would outdoors in a Rocky Mountain arid environment. This is because high tunnel temperatures and moisture levels are often optimum for organic matter decay.

Organic matter

A major advantage of organic nutrients is the fact that adding them increases soil organic matter. Organic matter can improve tilth, soil structure, bulk density, water holding capacity, and drainage as well as adding nutrients to the soil. Organic materials supply a mix of nutrients, often contributing secondary and trace nutrients as well as the important N, P and K. Organics are usually slow release and supply small but steady amounts of nutrient throughout the growing season. Organic materials contain natural chelating (pronounced key-lay-ting) compounds (complexing agents) that promote the availability of trace nutrients.

There are some disadvantages to using organic fertilizers. It is often difficult to measure the exact amount of a nutrient applied organically or determine when it will be available to the plants, as the materials may not be uniform. The balance of nutrients in organic materials may also be off and lead to excess buildup. This is especially true of composts and manures. Many organic fertilizers are low analysis materials and a large volume must be applied to provide adequate quantities for good plant nutrition. Finally, the cost of transporting and incorporating these materials can be substantial.

Table 5.2 Non-synthetic nutrients*

Source	Nitrogen	P_2O_5	K_2O
	%	%	%
Composted chicken manure	3.0	2.0	2.0
Separated dairy solids	1.5	1.0	0.6
Dry cattle manure	1.3	2.0	2.0
Horse manure w bedding	0.5	0.2	0.6
Blood meal	12-15	1	1
Fish meal	10	4	0
Bone meal	1-4	12-24	0
Rock phosphate	0	25-30	0
Cottonseed meal	6-7	2	1

* Sustainable horticulture for Wyoming – a master gardener handbook. 2004. University of Wyoming Extension.

Compost

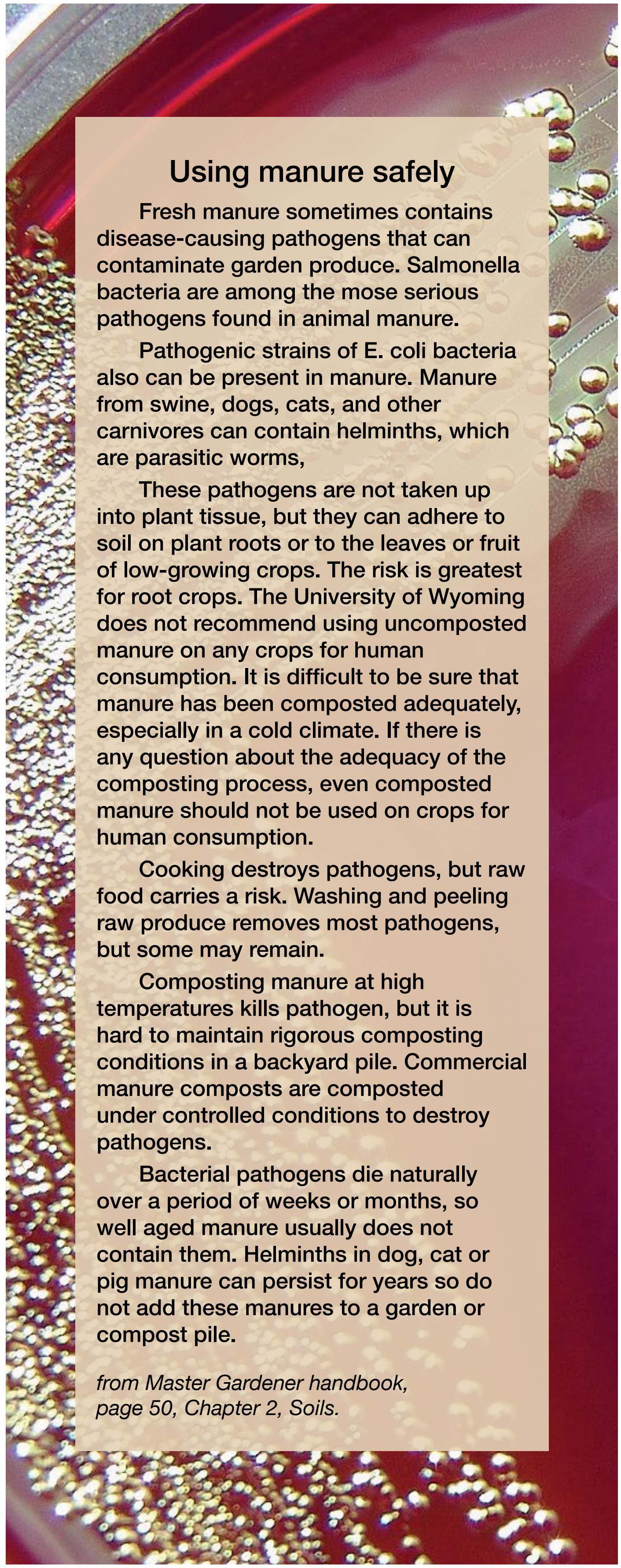
In nature dead plant and animal materials decay slowly and turn into a nutrient rich, soil amendment. Composting uses controlled temperature, oxygen, and moisture, while balancing the proportions of carbon rich (browns) and nitrogen rich (greens) materials to accelerate the natural decay. We use compost because it adds organic matter to the soil, which improves nutrient content, drainage and water holding capacity. A finished compost often has low nutrient content but will still greatly improve the quality of your soil.

A good compost is free of weed seeds, disease organisms and herbicide contamination. A good compost has a low to moderate salt content, a carbon to nitrogen ratio less than 35 (30 to 1 is recommended), a pH between 5.5 and 8 (6 to 8 preferred) and is low in pesticides that may harm crops.

The amount of compost you add will depend on your soil properties. Consider the salt tolerance of your crop (and succeeding crops) and the salt content of the compost you have available before you apply compost in the high tunnel. To maintain a healthy environment for all of your crops you should never let your soil electrical conductivity (a measure of salt content) get higher than 2.0 dS/m. This is especially important for salt sensitive crops like beans, carrots, strawberries, onions, roses, raspberries and parsnips. Transplants and seedlings of other crops will also prefer this low salt content. Mature plants of other crops can produce well at 3.0 to 4.0 dS/m. If your salt levels get too high flush your soil with 6 inches of low-salt irrigation water.

Manure

Manure has been used as a nutrient source for thousands of years. It is an excellent source of organic matter and provides many essential macro and micro nutrients. However, it should be used with caution. It must always be aged (6 months to a year) as fresh manure may damage your plants. Fresh manure may contain weed seeds, antibiotics, pesticides, high salt levels, and disease organisms. Fresh manure may have pathogens in it that can transfer among mammals. The USDA Organic standard requires that, after manure application, you must wait 90-120 days depending on the crop grown before harvesting crops for human consumption. Additionally, manure usually contains too much phosphorous for the amount of nitrogen it provides and frequent use will lead to a phosphorous build-up in your



Using manure safely

Fresh manure sometimes contains disease-causing pathogens that can contaminate garden produce. Salmonella bacteria are among the mose serious pathogens found in animal manure.

Pathogenic strains of E. coli bacteria also can be present in manure. Manure from swine, dogs, cats, and other carnivores can contain helminths, which are parasitic worms,

These pathogens are not taken up into plant tissue, but they can adhere to soil on plant roots or to the leaves or fruit of low-growing crops. The risk is greatest for root crops. The University of Wyoming does not recommend using uncomposted manure on any crops for human consumption. It is difficult to be sure that manure has been composted adequately, especially in a cold climate. If there is any question about the adequacy of the composting process, even composted manure should not be used on crops for human consumption.

Cooking destroys pathogens, but raw food carries a risk. Washing and peeling raw produce removes most pathogens, but some may remain.

Composting manure at high temperatures kills pathogen, but it is hard to maintain rigorous composting conditions in a backyard pile. Commercial manure composts are composted under controlled conditions to destroy pathogens.

Bacterial pathogens die naturally over a period of weeks or months, so well aged manure usually does not contain them. Helminths in dog, cat or pig manure can persist for years so do not add these manures to a garden or compost pile.

from Master Gardener handbook, page 50, Chapter 2, Soils.

Figure 5.2. New seedlings do not require fertilizing.

soil. You can compost manure to minimize the risk from weed seeds and disease organisms, but it is hard to maintain the appropriate composting conditions in Wyoming. The temperature in the compost pile must be maintained at 131 F to 170 F for 3 days using an in-vessel or static aerated pile. Manure should be avoided if anyone whose immune system is compromised is likely to eat produce from the high tunnel.

Inorganic fertilizer

Inorganic manufactured fertilizers are convenient and relatively easy to use. You can precisely measure the amount of these materials because they are uniform in concentration and particle size. The concentration of nutrients in these materials is usually several times the concentration of nutrients in the available organic fertilizers. Inorganic fertilizers are available as single nutrient products (21-0-0 or 0-0-60) and as blends (16-16-16). Micronutrients are available as inorganic salts such as ferrous sulfate and also as chelated products which can increase nutrient availability in our high pH soils. Information on salt index and acid/base potential is often on the label of the product box or bag. This allows you to choose products with appropriate properties for your soil conditions.

Inorganic fertilizers only increase organic matter by increasing plant growth. Many of them are also quick release and do not provide a slow but steady source of nutrient throughout the season. Several smaller doses throughout the season will ensure plants maintain steady growth rather than a single application.

Your Fertilizer Rights

Whether supplied in organic or inorganic forms, fertilizers are essential for good plant growth. When using fertilizers it is important

Use the following calculation to determine a fertilizer application rate:

Fertilizers are rated by percentage of available nutrients. Diammonium phosphate has a grade of 18-46-0 and would contain 18 percent nitrogen (N), 46 percent phosphorus (P2O5), and 0 percent potassium (K20).

Suppose you have one 10 lb bag of 16-20-0-24S. It would contain 1.6 pounds of N (10*0.16), 2 pounds of P2O5 (10*0.20), no potassium, and 2.4 pounds sulfur (10*0.24).

To calculate the amount of fertilizer you need:

$$\frac{\text{(Pounds nutrient needed) X 100}}{\text{\% nutrient in fertilizer}} = \text{pounds of fertilizer needed}$$

For example, if the fertilizer grade was 34-0-0 (34% N, 0% P2O5, 0% K20), and you needed 1 pound N/1000 sq ft, you would apply 2.94 pounds of fertilizer (34-0-0):

$$\frac{\text{(1 pounds N/1000 sq ft) X 100}}{\text{34\%}} = \text{2.94 pounds fertilizer (34-0-0)/1000 sq ft}$$

Figure 5.3. Determining the amount of fertilizer to apply requires a calculator.

to balance crop goals with economic goals, environmental concerns and social acceptance of the practices chosen. The International Plant Nutrition Institute (IPNI) promotes the use of the 4 R's; the right rate, the right time, the right source, and the right placement.

Right rate

A soil test can identify nutrient deficiencies before you plant your crop. Remember that in high tunnels you have an extended season and nutrients will be needed for a longer period of time than for a conventional field production system. Higher application rates can present toxicity problems so you will probably want to apply the nutrients in several small increments over the duration of the season.

Right time

In addition to the right rate, it is important to provide an adequate supply of nutrients when your crop needs them. Applying a mobile nutrient like nitrogen too far ahead of crop need can result in a loss of nutrient, which results in poor crop performance and wasted dollars spent on fertilizer. Dividing the season's nutrient supply into many small applications is a reasonable approach in the highly managed environment of a high tunnel.

Right source

You will need to decide if you want to go with organic, inorganic or a mix of the available nutrient sources. Some organic sources (compost, manures, alfalfa) can also provide a significant increase in the organic matter content of your soil. If you are building up salts you should choose a nutrient source with a low salt index. Some available nutrient sources are listed in the table 3.

Right placement

It is important to place your fertilizer where it is accessible to your crop because nutrients have different solubilities and mobilities which are affected by soil properties. You want to have efficient use of the available nutrient while preventing salt injury.

Some of the basic ways to apply fertilizer include broadcasting, banding, foliar feeding, and fertigation.

4R Nutrient Stewardship

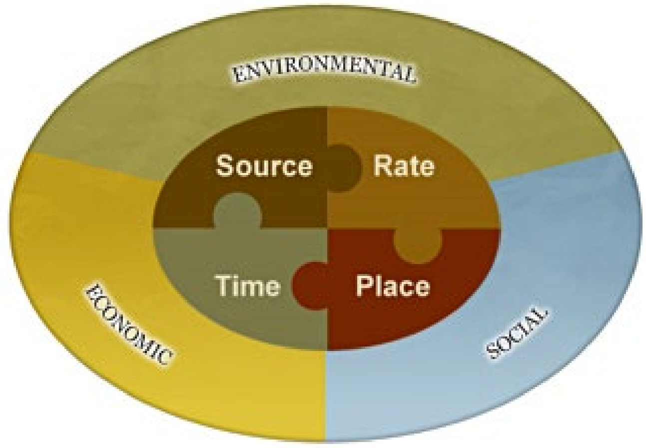


Figure 5.4. Plant nutrient interrelationships.

International Plant Nutrition Institute (IPNI)

Broadcast fertilization attempts to give an even distribution of nutrient in the soil. A uniform application is made and then incorporated into the soil. This often leads to inefficient use of immobile nutrients like phosphorous as much of the treated soil is never in close proximity to the plant roots.

Banding creates a concentrated supply of nutrient closer to where the plant will need them. Care must be taken to avoid too high a concentration of nutrient or the seed or plant may be injured. Banding is often a more efficient way of applying phosphorous fertilizer.

Foliar application is usually restricted to micronutrients. Caution must be taken to avoid application on days with high temperatures (>90 F) as leaf injury can result.

Fertigation, or applying nutrient in the irrigation water, is often accomplished through drip lines in a high tunnel operation. Microfertilization is often used because it is so convenient to do it this way. The required nutrients for the season are split into many small applications during the season and applied with the irrigation water. Organic and inorganic fertilizers that are soluble can be supplied this way.

For more comprehensive discussion of the four "rights" consult the IPNI website at http://www.ipni.net/4r.

Table 5.3. Commercial grades, main nutrient components, and form of some common fertilizers.

Fertilizer materials	Commercial grade	Main nutrient component	Other nutrients	Form
Nitrogen				
Ammonium sulfate	21-0-0	N	24% S	Dry
Ammonium thiosulfate	12-0-0	N	26% S	Fluid
Anhydrous ammonia	82-0-0	N		Compressed gas
Diammonium phosphate	16-46-0 to 18-48-0	N	46% P_2O_5	Dry
Monoammonium phosphate	11-52-0	N	52% P_2O_5	Dry
Urea	46-0-0	N		Dry
Urea-ammonium nitrate	32-0-0 or 28-0-0	N		Fluid
Phosphate				
Ammonium polyphosphate	10-34-0	P_2O_5	10% N	Fluid
Diammonium phosphate	18-46-0	P_2O_5	18% N	Dry
Monoammonium phosphate	11-52-0	P_2O_5	11% N	Dry
Triple superphosphate	0-45-0	P_2O_5		Dry
Potassium				
Muriate of potash	0-0-62	K_2O		Dry
Potassium sulfate	0-0-50	K_2O	18% S	Dry
Iron				
Ferous ammonium sulfate	14% Fe	Fe	8% S	Dry
Ferrous sulfate	20% Fe	Fe	11.5% S	Dry
Synthetic iron chelates	5-14% Fe	Fe		dry
Zinc				
Ammoniated zinc	13-0-0-15% Zn	Zn	13% N	Fluid
Synthetic iron chelates	6-14% Zn	Zn		Dry
Zinc ammonium sulfate	16% Zn	Zn	15.5% S	Dry
Zinc sulfate	35.5% Zn	Zn	12% S	Dry
Sulfur				
Gypsum	18.5% S	S	23% Ca	Dry
Elemental sulfur	100% S	S		Dry
Ammonium sulfate	21-0-0-24% S	S	21% N	Dry

6 IRRIGATION water management

Axel Garcia y Garcia and Abdel Mesbah

Introduction

The success of high tunnels (HT), also known as hoop houses, is directly related to the use of irrigation. A HT, a low-cost structure designed to extend the growing season and for intense production, must use irrigation water since it protects crops from snow and rain.

Within the different irrigation methods available in the market, drip or trickle irrigation is perhaps the most used for HT production systems. Drip irrigation is highly efficient and can also be used to inject the fertilizers needed by the crops of interest during the growing season.

Because of the inherent characteristics of the HTs, irrigation should be carefully planned. For example, HT crops usually need more water than field crops because they grow bigger and for a longer time. However, too little or too much water may be detrimental to your crop.

This chapter provides some general information regarding irrigation water management in HT production systems.

Suitable Irrigation Methods in High Tunnels

High tunnels can be for non-commercial or commercial uses. Based on our HT production goals (non-commercial or commercial) and our investment capability, irrigation of HTs can vary from systems as simple as a household hose to as complex as a fully automated drip irrigation method.

Although overhead sprinkler methods can also be used, the most suitable irrigation method for HT production systems is drip or trickle. Drip irrigation is more efficient than a conventional sprinkler system. It can be used in conjunction with plastic mulch by placing the drip lines underneath the plastic in order for the plants to receive optimum moisture (www.ms.nrcs.usda.gov/technical/SeasonalHighTunnels.html). Drip irrigation uses emitters and lateral lines on the soil surface or attached aboveground on a trellis or tree (Ayars et al., 2007) (Fig. 6.1.).

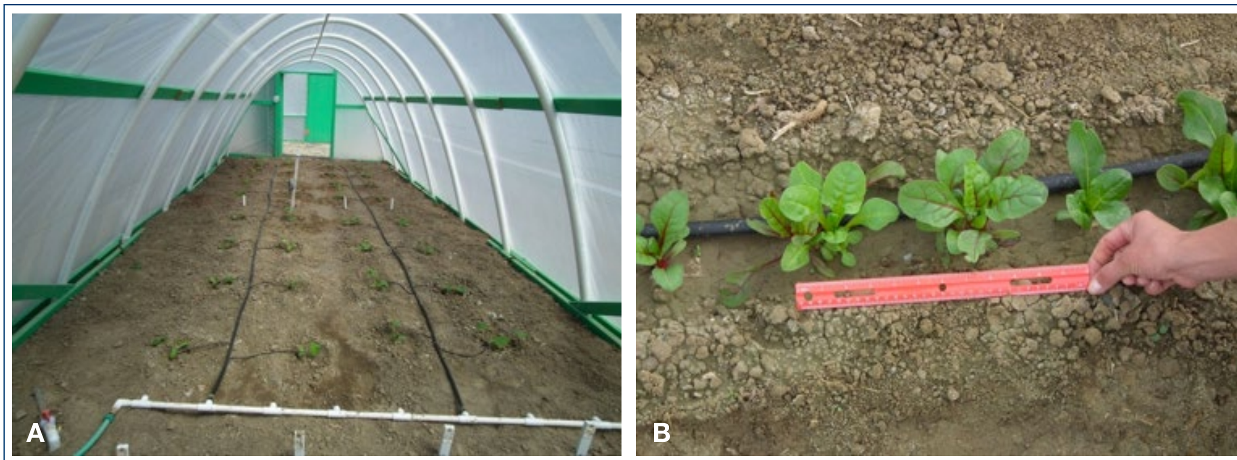


Figure 6.1. Drip irrigation in high tunnels at the University of Wyoming Research and Extension Center in Powell; a) spaghetti tubes and b) in-line emitter drip tubing.

Some advantages of the drip irrigation are: a) increased water use efficiency, b) improved crop yield and quality, c) improved fertilizer and other chemical application, and d) reduced risk of foliar diseases, among others (Ayars et al., 2007; www.ms.nrcs.usda.gov/technical/SeasonalHighTunnels.html).

The basic components of a drip system are: the pump unit, control head, main and submain lines, laterals, and emitters. The pump unit takes water from the source and provides the necessary pressure into the pipe system. The control head consists of valves to control the discharge and pressure in the entire system, filters to clean the water, and the inputs injection system. The mainlines, submains and laterals supply water from the control head to the field. The emitters are the devices used to control the discharge of water from the lateral to the plants.

If directly connected to a faucet at home (please check for special permit to use municipal water to irrigate a HT), the basic components of a drip system can be: a control valve, a backflow preventer, pressure regulator, filter, tape adapter, the drip tape and the emitters (included if in-line emitters). A flush system is not needed since the whole system may be removed at the end of the season for an easier soil preparation and to avoid freezing damage. Household water pressure is usually around 50 psi; so make sure to install a pressure regulator. Since drip irrigation is a low pressure system, lifting a water container to 4 – 6 ft above the ground should provide the necessary pressure to drip irrigate a HT as well.

Drip irrigation can operate with pressure as low as 8 psi; however, the system will operate better with pressures between 20-30 psi. The drip line can be placed on surface or slightly buried below the soil at a distance of 2-3 inches from the plant (Fig. 6.2.).

Drip irrigation comes in several options, so can easily be tailored to our needs. For example, we could choose spaghetti tubing or in-line emitter drip tubing (Fig. 6.1a and Fig. 6.1b). Emitters can be regular or pressure compensating. The former are pressure sensitive and deliver higher flow at higher pressure while the latter deliver the same flow regardless the variation on pressure. Most emitters are currently pressure-compensating, which allows for a better irrigation uniformity (Schwankl & Hanson, 2007).

Figure 6.2. Buried line in a high tunnel at the Powell Research and Extension Center.

Know Your Soil

The starting point for irrigation management is to get familiar with your soil. Information, such as texture, which refers to the relative amounts of sand, silt, and clay of the soil, can be used to determine the soil available water (AW); for example, a sandy soil holds less water than a clayey soil (Table 6.1.). This has a tremendous implication on irrigation since for the former we should apply short and frequent irrigation while for the latter irrigation should be less frequent.

Half of the soil volume is made of empty spaces; those empty spaces can be micro and macro pores. When the empty space of micro and macro pores is filled with water, the soil is saturated. The water in the macro pores can drain within hours or days (depends on the soils texture). When this happens, the soil is at field capacity (FC). On the other extreme, if the soil is too dry, the plants may wilt and die; this condition is called wilting point (WP). The difference FC – WP is the available water (AW) to plants.

Practically speaking not all AW is available to plants. For horticultural crops, the most common crops in HT production systems, a fraction of AW, between 0.20 – 0.50, should be used (Table 6.2.).

Table 6.1. Relation between soil texture and plant available water.

Soil Texture	Available Water (in/ft)
Sand	0.60
Loamy sand	1.10
Sandy loam	1.38
Loam	1.95
Silt loam	1.90
Sandy clay loam	1.30
Sandy clay	1.60
Clay loam	2.00
Silty clay loam	2.01
Silty clay	2.20
Clay	1.95

Adapted from http://ohioline.osu.edu/b472/0002.html, Brouwer et al., 1988, and www.dpi.vic.gov.au.

Table 6.2. Maximum rooting depth for irrigation scheduling and soil water depletion fraction for no stress conditions of various vegetable crops

Crop	Fraction of Soil Water Depletion	Crop	Fraction of Soil Water Depletion
Broccoli	0.45	Cantaloupe	0.45
Cabbage	0.45	Cucumber	0.50
Carrots	0.35	Squash, Zucchini	0.50
Cauliflower	0.45	Watermelon	0.40
Celery	0.20	Potato	0.35
Lettuce	0.30	Turnip	0.50
Green onions	0.30	Beans, green	0.45
Spinach	0.20	Artichokes	0.45
Radishes	0.30	Asparagus	0.45
Egg plant	0.45	Strawberries	0.20
Bell pepper	0.30	Sweet corn	0.50
Tomato	0.40	Berries (bushes)	0.50

Source: Allen et al., 1998.

Know Your Crop

Different plants need different amounts of water. The growing season also determines the amount of water to be applied. For instance, during fast growing stages, specifically spring and summer, water requirements are high and daily irrigations could become common. Conversely, early (Feb - Mar) and late (Sep-Oct) plantings means short and cold days. By then, little irrigation is required and irrigation water amounts should be adjusted.

Among other factors, the root depth determines how often a crop should be irrigated. Vegetable crops, for instance, have a shallow rooting system (Table 6.3.).

Most vegetable crops are 60% – 90% or more water. As a result, these crops require a consistent supply of water throughout the growing season. If different type of crops are planted in the same space, a common practice in HT production systems, irrigation water needs to be supply as often as the most demanding water crop we have.

Figure 6.3. The end result of proper soil moisture management.

If so, soil moisture should be carefully monitored for saturated soil conditions or for raising humidity (called relative humidity) in the HTs to avoid potential problems with pests and diseases. As a rule of thumb, RH of 80% or more in the HT should be limited to a period of time as short as possible.

Table 6.3. Rooting depth of various vegetable crops.

Shallow-Rooted (Up to 1 ft)	Intermediate (1 -2 ft)	Deep-Rooted (2+ ft)
Celery	Artichoke	Asparagus
Lettuce	Broccoli	Egg Plant
Onions	Beans, snap	Cantaloupe
Radishes	Berries	Cucumber
Spinach	Cabbages	Parsnips
Strawberries	Carrots	Peas
	Cauliflower	Pumpkins
	Cucumbers	Sweet corn
	Peppers	Watermelons
	Potatoes	Winter squash
	Tomatoes	
	Turnip	
	Zucchini, Squash	

Allen et al., 1998

Irrigation Scheduling

Irrigation scheduling is about when to irrigate and how much water to apply. Methods for irrigation scheduling vary from as simple as "feeling" the moist conditions of the soil to as complex as computer-based systems. Due to their simplicity, we discuss here the use of the "feel" method (USDA-NRCS, 1998) as well as some chart- and soil-based methods that use soil moisture monitoring sensors, including tensiometers and watermarks.

The Chart Method

Crops available water can be determined combining the information from tables 6.1. and 6.2. For example, if the soil of a HT has a silt loam texture, the available moisture will be 1.90 in/ft (Table 6.1). Assuming that we planted spinach in early March, tomatoes in late June, and lettuce in late September, the average rooting depth of our crops will be 1.0 ft for spinach and lettuce and 1.5 ft for tomato (Table 6.2). Then, our available water will be 1.90 in/ft x 1.0 ft = 1.90 in of water for spinach and lettuce and 1.90 in/ft x 1.5 ft = 2.85 in of water for tomato. Spinach will be allowed to use a fraction of 0.20 of AW; that's, 1.90 in x 0.20 = 0.38 in of water in 1.0 ft of soil. Tomato will be allowed to use a fraction of 0.40 of AW = 2.85 in x 0.40 = 1.14 in of water in 1.5 ft of soil. Lettuce will be allowed to use a fraction of 0.30 of AW = 1.90 in x 0.30 = 0.57 in of water in 1.0 ft of soil.

As previously mentioned, HT crops use more water than field crops. For HTs conditions installed at the University of Wyoming Research & Extension Center in Powell, WY, the daily average water use for spinach, tomato and lettuce is around 0.15 inches in April, 0.30 inches in July, and 0.15 inches in October, respectively. Thus, spinach should be irrigated every 0.38/0.15 = 2 days, tomato every 1.14/.30 = 4 days, and lettuce every 0.57/0.15 = 3 days.

Notice, however, that the above example assumes average conditions. In fact, crops' water requirements vary daily as a function of the plant's growth stage, rooting depth, environmental conditions, among other factors. As a rule of thumb, the critical irrigation period of a plant is at the beginning of the flowering stage. Some exceptions are sweet corn (at silking) and celery, lettuce, and spinach which need continuous irrigation.

The Feel Method

The Feel-based method determines when to irrigate and how much water to apply by hand squeezing a soil sample (USDA-NRCS, 1998). Details regarding the "Feel" method procedure can be found at: fttp://ftp-fc.sc.egov.usda.gov/MT/www/technical/soilmoist.pdf.

Soil moisture conditions using the Feel method can be estimated, with experience, to an accuracy of about 5 percent. Soil moisture is typically sampled in one foot increments to the root depth of the crop. The Feel method involves:

Obtaining a soil sample at the selected depth using a probe, auger, or shovel;

Squeezing the soil sample firmly in your hand several times to form an irregularly shaped "ball";

Squeezing the soil sample out of your hand between thumb and forefinger to form a ribbon;

Observing soil texture, ability to ribbon, firmness and surface roughness of ball, water glistening, loose soil particles, soil/water staining on fingers, and soil color.

Comparing observations with photographs and/or charts to estimate percent water available and the inches depleted below field capacity.

Tensiometers

Tensiometers are probes that measure the soil suction (force needed to remove the water from the soil). Tensiometers don't need calibration and indirectly measure the actual soil moisture content by relating the soil suction and the available soil water content.

A tensiometer is a plastic tube with a porous ceramic tip at one end. The tube is filled with water and sealed with a cap. Before installation, the entrapped air has to be removed. Some

Figure 6.4. Irrigation scheduling using tensiometers in high tunnels planted with a) cucumber and b) tomatoes at the Powell Research and Extension Center.

tensiometers have an attached vacuum gauge and others an electronic device that can be used from one probe to another. Tensiometer readings are in centibars (cb) or kilopascals (kPa), which are equivalent; the larger the number, the drier the soil. When to irrigate is a function of soil texture and crop type. Generally speaking, irrigation should be triggered when tensiometer readings are 10–30 cb. Tensiometers' length vary from 6 in to 48 in and cost from around $60 to $90 each.

A research project conducted at the University of Wyoming Research & Extension Center located in Powell, WY began using tensiometers to monitor soil moisture and manage irrigation (Fig. 6.4). Tensiometers were installed at 6 and 12 in depth at three HTs of different shape, each planted with a different crop.

Watermarks

Watermark sensors use electrical resistance to indirectly measure the actual soil moisture content as related to soil water tension. The sensors consist of a pair of highly corrosion resistant electrodes that are imbedded within a granular matrix. An electrical current is applied to the Watermarks to obtain a resistance value. The Watermark is designed to be a permanent sensor, placed in the soil to be monitored and "read" as often as necessary with a portable or stationary device (www.irrometer.com). Similar to tensiometers, Watermarks are affordable devices to monitor soil moisture; each sensor costs around $40 + $330 for the meter, which can be used for several sensors.

Water Quality

The quality of the irrigation water is important not only for the crop but also for the irrigation system. All irrigation water contains dissolved mineral salts; their concentration and composition vary as a function of the irrigation water source and time. It's therefore highly recommended to take water samples and send for lab analysis to determine the necessary measures to reduce problems. Analysis should be done for horticultural or agronomic use and not human consumption.

One of the most common problems related to the quality of the irrigation water is salinity. A salinity problem exists if salt accumulates in the crop root zone to a concentration that causes a loss in yield. Salts are added to the soil with each irrigation. A portion of the added salt must be leached from the root zone before the concentration affects crop yield. Leaching is done by applying sufficient water so that a portion percolates through and below the entire root zone carrying with it a portion of the accumulated salts.

Another problem related to water quality is clogging due to algae growth and precipitates of calcium and magnesium carbonates. The injection of small amounts of household bleach (5.25% active chlorine) may be the most affordable and easiest way to prevent clogging issues. It should be noted though that the use of chlorine is dangerous; Read the label for proper handling and protective equipment like gloves and masks.

Some Tips for Irrigation Water Management in High Tunnels

1. Apply a "heavy" irrigation at the beginning of the season to bring the HT soil near or at FC.
2. Throughout the growing season, keep your soil moisture near field capacity.
3. Animals could chew on drip irrigation lines; so, make sure you routinely check your systems
4. If a multi-crop HT, plan your irrigation for the crop with higher water requirements.
5. Maintain a regular checkup of your drip tape to make sure you won't have plugged emitters.
6. Know the pH of your water to keep your system in a good health and performance.
7. Make sure you winterize your irrigation system before the first freeze.

References

Allen, R.G., L.S. Pereira, D. Raes, M. Smith. 1998. Crop evapotranspiration - Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56. FAO, Rome.

Ayars, J.E., D.A. Bucks, F.R. Lamm, and F.S. Nakayama. 2007. Chapter1: Introduction. In: Microirrigation for crop production: design, operation, and management. F.R. Lamm, J.E. Ayars, F.S. Nakayama (eds.). Elsevier, Development in Agricultural Engineering 13, 618p.

Brouwer, C., K. Prins, M. Kay, and M. Heibloem. 1988. Irrigation water management: irrigation methods. Training Manual No. 5, FAO, Rome.

Schwankl, L.J and B.R. Hanson. 2007. Chapter 12: Surface Drip Irrigation. In: Microirrigation for crop production: design, operation, and management. F.R. Lamm, J.E. Ayars, F.S. Nakayama (eds.). Elsevier, Development in Agricultural Engineering 13, 618p.

USDA-NRCS. 1998. Estimating soil moisture by fell and appearance. Program Act No. 1619, 6p. Available online at: ftp://ftp-fc.sc.egov.usda.gov/MT/www/technical/soilmoist.pdf. Last access: December 15, 2011.

Figure 6.5. Drip irrigation works well for most crops grown in high tunnels.

7 ORGANIC PRODUCTION in High Tunnels

Kelli Belden

Organic production is both a federal law and a philosophy. In the United States "organic" is a legal labeling term that refers to an agricultural product produced in accordance with the Organic Foods Production Act (OFPA) under Title 21 of the 1990 Farm Bill and the regulations in the Act. If the product is not produced in accordance with the Act it may not be called organic.

Philosophically, organic is often interpreted as something that has minimal contamination or toxic chemicals and is in balance with nature. The basic organic principles are biodiversity, integration of production practices (animal and plant production joined), environmental sustainability, natural plant nutrition, integrity of the organic product, and natural pest management. Organic practices include the use of rotations, green manure, cover crops, animal manure, compost, intercropping, mulching, natural pesticides, bio-controls and buffer strips. Organic management replaces many chemical controls with intensive monitoring and physical intervention (hand weeding, hand insect removal etc.). Conversion to an organic system will benefit from the extra hands on effort that is characteristic of good high tunnel management.

Federal regulations are designed to prevent contamination and commingling. Contamination is any physical contact of a prohibited or unacceptable materials or products with an organic product. Commingling is any physical contact between unpacked, organically produced, agricultural products and non-organic products during production, processing, transportation, storage or handling.

Except for operations with less than $5,000 in receipts, you must be certified for compliance with the Federal Rule by an independent certifying agency if you want to use the labels "100 percent organic" "organic" or "made with organic". Operations with less than $5,000 in receipts must follow the same rules and keep the same records as certified producers, and must be able to produce them if asked to show compliance, but they do not need to be inspected and certified by an independent agency.

It should be noted that the Act is a living document that is updated frequently: a practice or product that was valid one year may not be valid the next. It is the producer's responsibility to keep informed about any changes and to adjust his or her practices accordingly. Some of the information in this section may become obsolete the next time the rule is updated.

Organic Certification

Certification requires an Organic System Plan. The plan must identify the operation physically and operationally. All inputs, processes, and outputs must be documented by a verifiable audit trail. The plan must identify all substances used: their composition, source, location of use and documentation of availability. The plan must identify all monitoring practices and procedures and the frequency of their verification by the producer. Physical barriers that prevent commingling or prohibited contact must be identified. Management practices (rotations, fertility, irrigation, tillage, pest control) must be described. A description of the record keeping practices which are sufficient in detail to be readily

Figure 7.1. Raised bed production in a high tunnel in Wheatland. (Photo: Jeff M. Edwards)

understood and audited needs to be included. The records must be maintained for five years and contain sufficient information to demonstrate compliance with the Act.

Planning for organic production starts with the land. The soil must be managed organically for 3 years before the first harvest can be certified. Sufficient land area must be available to allow for buffer zones between organic and non-organic sites. Soil fertility practices must maintain or improve the physical, chemical and biological health of the soil. Nutrients can be managed through the use of crop rotations, cover crops, the application of fertilizers approved for organic use, and the application of approved plant and animal materials. Objectives are to improve organic matter and soil quality, and to prevent contamination. Buffer zones can be somewhat smaller since the vents can be closed, minimizing the potential for drift contamination from conventional sites that may be near your tunnel. It is important to remember that with the extended growing season in a high tunnel, nutrient removal from the soil will be accelerated. The establishment of permanent beds in your tunnel can facilitate the addition of organic matter to your soil as the application is area is confined and maintained over time.

Compost is frequently used and must meet certain requirements. The carbon to nitrogen ratio (C/N ratio) must be between 25:1 and 40:1. The compost must be held at 131 to 170 F for 3 days in a vessel or static aerated pile. If a windrow is being used for composting, it must be held at 131 to 170 F for 15 days and the pile must be turned 5 times. Un-composted plant materials may be added to the soil at any time. You may use un-composted manure if 120 days will pass before harvesting of any product that may have transient contact with the soil. This includes produce that grows on vines like tomatoes. Soil nutrient amendments may include synthetics from the National list cited by the Act, mined substances of low solubility, mined substances of high solubility if used in compliance with the non-synthetic list cited by the Act, and plant and animal material that has not been altered by a manufacturing process.

Seeds and planting stock are your next concern. You must use organically produced seeds unless none are commercially available. Price is not a consideration. You must be able to document that no organic seeds were available. If none are available, you may use conventional seeds as long as there has been no treatment with a prohibited substance. For perennial planting stock you may use conventional as long as they have been managed organically for one year and no prohibited substances have been used. Occasionally, the federal government may require a specific treatment with a prohibited substance to combat a pest problem. If this occurs you need to maintain documentation of the temporary waiver of the rule.

Crop rotation must be implemented. This helps to maintain and improve organic matter as well as being a vital tool in pest management. It can also help with managing your nutrient status.

You must use organic practices to prevent pests and diseases. You will not pass a certification inspection by becoming "organic by neglect". Good management practices such as crop rotation, sanitation, use of resistant crop varieties, and any cultural practices that promote plant health should be included in your management plan. Pests may be controlled by mechanical or physical means, by using pest predators and pest parasites, and by using organically allowed lures, traps, pesticides or repellants. Small alterations in your original high tunnel design can make big differences in insect management. The addition of screening on tunnel vents can cut down on insect migration into your tunnel. The screening will also aid in retaining beneficial insects that you may be introducing into your tunnels.

Weeds may be controlled by mulching with biodegradable materials, by mowing, by hand weeding and mechanical cultivation, with flame or heat, and with approved plastic or synthetic mulches if removed from the field at the end of the season. Targeted irrigation using drip tape, and the rain excluding nature of tunnels will suppress many shallow-rooted weeds.

Diseases can be controlled by non-synthetic biological or botanical inputs and by using resistant varieties. If prevention and primary control methods fail, substances on the National List of Synthetics cited in the Act may be used, but conditions for use must be documented in your plan.

Your audit trail is the last vital part of your program. Everything you do throughout the year must be documented. Seed source certifications, receipts or documentation for all inputs showing suitability for organic production, equipment sanitation, storage records sales records, and transportation records all need to be maintained. Remember all parts of your operation are subject to inspection, even areas that are not part of your organic program.

After you pass your initial certification you must undergo inspection every year.

For more information on organic production consult the following.

- USDA – National Organic Program. www.ams.usda.gov/AMSv1.0/nop
- ATTRA - A sustainable agriculture information center that provides technical assistance to farmers, market gardeners and extension agents. www.attra.org
- OMRI - An organization that maintains lists of allowed, regulated and prohibited substances. www.omri.org

8 Growing VEGETABLES in High Tunnels

Karen Panter

High tunnels are great tools for earlier production of vegetable crops in the spring and, with minimal effort, almost year-round. Many vegetable crops can be grown including tomatoes, cool-season leafy greens, green beans, cucumbers, herbs, cole crops, crucifers, and squash. Each crop has its own set of environmental requirements that may be difficult to fulfill in Wyoming's climate. The following table includes important temperatures for growing vegetables in Wyoming.

Table 8.1.

	Air temperatures for vegetable growth			Minimum soil temperatures for vegetable growth
Crop	**Minimum (°F)**	**Optimum (°F)**	**Maximum (°F)**	**Temperature (°F)**
Bean, snap	50	80-90	100-110	48-50
Cabbage	40	60-65	75	38-40
Carrot	45	60-65	75	39-41
Corn	50	85-90	100-115	60-65
Cucumber	48-50	75-80	95-105	55-60
Eggplant	60	70-85	95-100	55-60
Lettuce	45	60-65	75	40-45
Melon	59-65	86-98	110-120	55-60
Onion	45	55-75	85	34-36
Pea	38-42	50-60	70-75	34-36
Pepper	60	70-80	95-100	55-60
Potato	43-45	50-60	80-90	39-41
Radish	40	60-65	75	48-50
Tomato	55-56	59-68	72	50-55

Figure 8.1. Variations in soil temperatures lead to uneven seed germination and plant growth.

Vegetables to Grow in High Tunnels

Cole crops

Cole crops are a group of vegetables that includes cabbage and kale. These are most often grown from transplants rather than direct-seeded into the tunnel. Start the seeds about five to six weeks before planting them in the high tunnel. Space them about 18 inches apart. They can also be started in late summer for a fall crop, but late summer high temperatures can delay crop maturity.

Cabbage can be quite variable in time to maturity, anywhere from 70 to 120 days, depending on the cultivar. Kale is somewhat quicker, taking about 55 days. Cabbage and kale should be harvested when the heads are the optimum size for the variety and leaves are tight.

Cruciferous crops

Crucifers include broccoli and cauliflower and are generally grown from transplants. Seeds should be sown five to six weeks prior to transplanting. When planted in a high tunnel, they should be spaced 12 to 18 inches apart, depending on the cultivar. There are a large number of both broccoli and cauliflower cultivars from which to choose.

Broccoli is usually ready to harvest after 60 to 85 days while cauliflower can take up to 90 days. Harvest broccoli when the florets are full and green but the yellow flowers are not open. For cauliflower, cover the heads with the top foliage to keep the florets white (unless it's a green cultivar). Harvest cauliflower when the heads are fully formed but not flowering.

Cucumbers

All sorts of cultivars of cucumbers are available. They should be direct-sown in a high tunnel since they do not transplant well. Cucumber seeds will germinate in about one week.

Cucumbers need lots of space plus support for the vines. Plants should be spaced 18 inches apart within rows and 3 feet between rows. The vines can easily reach 6 feet in length and should be grown vertically on wire fencing, nylon cord, or heavy twine. Grow them upward initially on the twine, then lower the vines as they grow to make harvesting easier.

Cucumbers take 50 to 70 days to reach maturity from sowing. Harvest when the size and color are optimum for the variety.

Green beans

As with tomatoes, there are numerous cultivars of green beans available. Bean seeds should be direct-sown in the soil in the high tunnel and will germinate in about one week. Space them at 3- to 4-inch intervals, depending on the cultivar, with rows spaced 12 to 14 inches apart.

Pole beans need some type of support or trellising system on which to climb. Bush types, however, don't need additional support. Watch water needs carefully, especially near flowering, as high temperatures in high tunnels can cause flower drop, poor set, or incomplete pod filling.

Bush beans typically will be ready to harvest after about 48 to 60 days. Pole beans take longer, from 58 to 70 days. Harvest green beans when the pods are full and still tender.

Herbs

Many herb seeds, such as basil, cilantro, and chives, can be direct-sown in the tunnel in spring, about a month earlier than in the field. Other herb seeds should be grown from transplants (oregano, thyme, etc.) since they are perennials.

Many different cultivars of herbs exist. Read seed package or transplant labels to determine if the cultivar is right for you. Space plants according to the directions on the seed package or the transplant label.

Herbs are normally harvested just before flowering for best flavor.

Leafy greens

Seeds of leafy salad greens should be direct-sown in rows or small patches in the tunnel. Keep in mind, however, that soil temperature in spring is very important for germination. Seeds won't germinate well until soil temperatures reach at least 40° F. It will usually take them about one to two weeks to germinate, depending on the type and time of year. Greens typically include lettuce, spinach, arugula, etc. Growers can expect to start harvesting leafy greens 40 to 50 days after sowing. These are normally harvested when leaves are young and tender.

Squash

Squash should be direct-seeded in the soil in the high tunnel since most types of squash do not transplant well. Seeds will germinate in one to two weeks.

These plants will need large amounts of space, about 24 inches apart within rows for summer squash (such as zucchini) and about 2 ½ to 3 feet apart for winter squash (like butternut) with about 3 feet between rows. The vines, like those of cucumbers, can easily reach 6 feet long and are best grown vertically on supports for climbing. These supports can be similar to those used for cucumbers.

Summer squash will take 40 to 50 days to maturity while winter squash takes much longer, 80 to 120 days, depending on the cultivar. Harvest all types of squash when maturity for the variety has been reached.

Figure 8.2. Tomatoes are just one of many vegetable crops suited for high tunnels.

Tomatoes

The number of tomato cultivars available is staggering. It's generally best to use transplants spaced 12 to 24 inches apart, depending on the cultivar. Plants should have several sets of true leaves and may have a few flowers on them. Root systems should fill the container. Start seeds six to 10 weeks before transplanting into the tunnel. Start them in a warm location, but direct-sowing in a tunnel is not recommended.

It is highly recommended growers use determinate (bush-type) cultivars and support them with tomato cages or the less-expensive alternatives of bamboo stakes and sturdy twine. Alternatively, indeterminate (vining) cultivars are available and can be grown on twine strung vertically along horizontal wires attached to posts. The twine is lowered as the vines grow, making accessing the fruit easier.

Tomatoes typically take 60 to 85 days from planting to harvest, depending on the cultivar. Harvest tomatoes when full color has developed.

Numerous other vegetables can be grown in high tunnels. Those included here are the most common.

For More Information

- Maynard, Donald N. and George J. Hochmuth. 2007. *Knott's Handbook for Vegetable Growers*. Fifth Edition. Wiley & Sons, Hoboken, New Jersey.
- Nau, Jim. 1999. *Ball Culture Guide: The Encyclopedia of Seed Germination*. Third Edition. Ball Publishing, Batavia, Illinois.
- High Tunnels website. Utah State University. http://extension.usu.edu/productionhort/htm/tunnels

9 Growing SMALL FRUIT CROPS in High Tunnels

Karen Panter

Small fruits can be grown in high tunnels but tend to be tricky since they stay in the ground several years. Small fruits are perennial plants and in a high tunnel will still be exposed to cold temperatures, but exposure to wind and snow will be less than outdoor plants. Originally, strawberries were about the only small fruit grown heavily in high tunnels. Growers can also produce raspberries and blackberries. Blackberries are not usually recommended for outdoor production in Wyoming due to our alkaline soils, dry air, and cold winters but may be suited to high tunnel production. Blueberries have very specific growth requirements (acidic soils, high humidity) and thus are not recommended for either outdoor or high tunnel production in Wyoming. High tunnels can modify the environment and extend the growing season a month or more on either end.

General production recommendations are similar to field production with minor changes. For example, irrigation timing and the amounts of water required may be different, possibly less than in the field due to decreased exposure to drying winds. Watering may have to be more frequent than in the field during mid-summer if a high tunnel is open all the time for ventilation. Fertilization needed may differ as well, depending on the growth rate of the plants inside. Pruning techniques may vary, depending on the fruit. Finally, pesticide usage typically decreases in high tunnels for the most part; however, fungicide use may increase due to higher relative humidity inside the tunnel leading to higher incidence of certain diseases.

Small Fruits for Production in High Tunnels

Raspberries

Initial plantings of raspberries can be planted about one month earlier in high tunnels than outdoors. Since tunnels generally stay warmer, the soil can easily be worked and prepared earlier than in the field. Soil for raspberries should be moderately fertile and well-drained with a pH around 7.

Summer bearing raspberry cultivars (floricanes) are not recommended for high tunnel use. Winter injury is a problem, and production does not occur much earlier in tunnels than outdoors.

Fall bearing cultivars (primocanes) of raspberries produce their crops in late summer or early fall and produce well in high tunnels. These cultivars include ‘Autumn Bliss’ and ‘Heritage’. A grower could plant early fall bearers such as ‘Polka’, ‘Joan J.’, ‘Polana’, or ‘Autumn Britten’ where the growing season is short. A grower could also plant late-fruiting types, such as ‘Josephine’, to extend the fall season.

Generally, raspberries are planted at about 1 cane per 2 feet of linear row with rows about 6 feet apart. There should be enough room between rows for people to easily work with the plants, especially during harvest.

Harvest berries three times a week when they can be easily removed from the receptacle. They will usually be ready to pick about one month earlier than in field.

Black and purple raspberries are generally summer bearing may not be suited to Wyoming’s winter extremes.

Strawberries

Strawberries can be harvested three to five weeks earlier in the high tunnel than in the field. Also, they are reliable and prolific producers. Strawberries grow well in well-drained, moderately fertile soils at a pH of about 7.

June bearing types produce one crop of berries in June/July. Cultivars of June bearers include 'Chandler', 'Camarosa', and 'Sweet Charlie'. The June bearing strawberry season isn't necessarily lengthened by planting a variety of cultivars with different maturity dates. A grower could extend the harvest season by growing some in high tunnels and some in the field. Everbearing types are not recommended for growing in high tunnels, but day neutral types are. Day neutral types produce almost continuously through the growing season as long as temperatures can be kept below 85°F in the tunnel. Current cultivar recommendations include any of the California day neutrals, plus 'Seascape' and 'Albion'. 'Albion' is less heat tolerant than the others.

Strawberry plants should be spaced 12 to 15 inches apart in rows 1 to 2 feet apart. When planting, avoid covering the crown of the plant with soil. The midpoint of the crown should be level with the soil surface, and the top root should be just below the soil surface. The preferred system for growing strawberries in high tunnels is the annual hill system. In this system, plants are spaced 12 to 15 inches apart within rows in staggered rows about 12 to 15 inches apart. The beds can either be level or raised 8 to 12 inches and covered with black or white plastic mulch.

Harvest should occur at least every other day during times of peak production. Always pick strawberries when ripe otherwise they will simply rot on the plant.

Blackberries

Since blackberries are less tolerant of temperature extremes, they may not be good candidates for high tunnel production. Winter injury is sure to be a problem. One way to grow blackberries in high tunnels is to use a cold-hardy long-season, erect type such as 'Chandler' as it will stay in production longer. Another method is to use fall-bearing types that do not need winter protection. These would include 'Prime Jim' and 'PrimeArk45' but be advised they are thorny.

Cultivars can be either thorned or thornless, erect, semi-erect, or trailing. Trailing types can be either thorned or thornless. Thorned cultivars often do not require any trellising and produce fruit two to three weeks earlier than thornless cultivars. They also tend to be sweeter. Thorned cultivars include 'Cheyenne', 'Shawnee', and 'Choctaw'. Those without thorns include 'Chester', 'Hull', and 'Navaho'. Soil requirements are similar to those for raspberries.

Thorned blackberry cultivars should be planted 5 feet apart within rows. Rows should be wide enough for easy movement between them - at least 8 feet. Trailing thorned blackberries should be planted about 4 to 5 feet apart within a row. Rows should be about the same distance apart - 4 to 5 feet.

Fruits tend to turn black before they are completely ripe, and unripe fruits are very sour. Harvest blackberries several times a week when the fruit is easily removed from the stem. Blackberries, unlike raspberries, stay attached to the receptacle, which is the core of the berry fruit.

Blueberries

These small fruits are typically grown in geographic areas where the soils are quite acidic. Blueberries should only be grown in Wyoming by those with unlimited finances and time. These plants generally will not tolerate Wyoming's high pH, low organic matter soils, or our dry air and are not recommended for production here, even in high tunnels.

Figure 9.1. Many small fruits can be grown in high tunnels but beware of blueberries.

10 Growing CUT FLOWERS in High Tunnels

Karen Panter

The most common cut flowers used in the United States are now imported from growers off-shore. Much of this production occurs in Central and South America, China, Israel, Japan, and Europe. These major crops include roses, carnations, chrysanthemums, and alstroemeria. Specialty crop growers in the U.S., including those using high tunnels, now grow many of the minor, less commonly grown cut flowers. High tunnels are used in many countries to keep rain and wind off flowers. American growers now produce cut flowers that are less easily stored and shipped.

The advantage of high tunnels for cut flowers is that growers can plant as much as one month earlier than in the field and can produce a crop one to two months longer in the fall. Because tunnels protect from wind and rain, taller flowers can be produced, and flower quality is improved since they are not exposed to the elements.

A large variety of cut flower species can be grown in high tunnels, including annuals, perennials, and woody plants, along with geophytes (underground storage organs like bulbs, corms, rhizomes). In the spring, cool crops can be grown following a crop of cut tulips, which can be started in the fall in plastic crates. Their cold requirements are met during the winter, and the crop is cut the following spring. After the tulips are harvested, crates can be removed and annuals can then be planted. Some of these annuals include *Lisianthus*, *Trachelium*, *Celosia*, *Antirrhinum*, *Matthiola*, *Helianthus*, *Godetia*, and *Amaranth*.

There are challenges growing cut flowers in a high tunnel. One is daylength sensitivity of some species. Short-day plants, such as chrysanthemums, may bloom too early due to longer nights early in the season. Some plants may flower three weeks too soon and may produce much smaller flowers than normal. There is a related end-of-season problem with long-day plants in that they may produce few flowers if planted midsummer. Many of these are better planted in spring.

Soil preparation before planting is crucial. Follow soil preparation steps in that chapter of this handbook. For watering, irrigation is typically handled using drip systems. Follow setup guidelines for drip irrigation in that chapter of this handbook.

Annuals to Grow for Cut Flowers in High Tunnels

Tulips (*Tulipa* spp.)

Though not normally thought of as annuals, tulips can be forced for cut flower production. Spring tulips can be grown in plastic crates in a high tunnel. Always buy the largest size bulb possible. At least 10/11 centimeter (cm) circumference bulbs are recommended. Plant the bulbs at 6-inch spacing with about 5 to 6 inches of soil above the top of the bulb.

Non-pre-cooled bulbs should be planted in the fall since they must be exposed to at least six weeks of 40° F temperatures for flower buds to form. If you buy pre-cooled bulbs, they can be planted in the spring, in high tunnels, or greenhouses. Tulips should be treated as annuals, meaning they should be replanted each year.

After cold temperature treatments and depending on the cultivar, it may take four weeks before flowers are ready for harvest. Cut tulip flowers when they are almost completely colored. They may need to be cut several times a day to catch them at their optimum stage of opening.

Snapdragons (*Antirrhinum majus*)

Snapdragons are normally started from seeds and then transplanted into the high tunnel.

Young plants can be transplanted about six weeks after sowing, when the seedlings can be handled easily. Alternatively, growers can buy pre-germinated plugs from specialty propagators.

Seedlings can be planted in high tunnels as soon as air temperature is consistently 30° F or above. Snapdragons can handle temperature dips to 25° to 28° F but not for extended periods of time.

Cultivars in the 'Rocket' and 'Potomac' groups are recommended for cut flowers. They should be planted at 9- to 12-inch spacing. Count on 90 to 100 days from sowing seeds to harvest, depending on cultivar. Harvest stems when one-third to one- half of the flowers are open on each stem. Always keep the stems vertical as the tips will curve upward if the stems are laid horizontally.

Figure 10.1. Snapdragons are excellent fresh cut flowers.

Stock (*Matthiola incana*)

Stock plants are also usually started from seeds and then transplanted into a high tunnel.

Young plants can be transplanted into high tunnels after four to six weeks. Pre-germinated plugs can also be purchased from specialty propagators.

Stock prefers cool nights in the 50° to 55° F air temperature range for best flowering. If temperatures are above about 65° F, flowering is often delayed or blocked. Plants should be spaced 6 to 10 inches apart. It may take 90 days from sowing to harvest, depending on the cultivar. Flower stems should be harvested when about half of the flowers are open on each stem.

Sunflowers (*Helianthus annuus*)

All sunflowers are grown from seeds started two to three weeks prior to planting in the high tunnel. They require warmer air temperatures of 65° to 75° F for optimum growth and flowering.

Most sunflower cultivars flower faster under short day lengths, but some are day neutral.

Sunflowers should be planted at 6 to 12 inch spacing, depending on the cultivar. From sowing to harvest usually takes about 60 to 80 days, depending on the cultivar. They should be harvested when flowers are almost completely open.

Figure 10.2. Sunflowers can be grown in high tunnels, but cultivar selection is important. (Photo: Karen Panter)

Godetia (*Godetia amoena*)

All godetia are grown from seeds started three to four weeks before planting into high tunnels. Pre-germinated plugs can be purchased from specialty propagators.

Godetia is definitely a cool-temperature crop and does not tolerate high air temperatures.

Optimum night temperatures are 50° to 55° F with day temperatures below 75° F.

Plants can be grown either pinched or unpinched. Pinching is simply removing the growing point at the tip of the main stem and will result in several side stems per plant. Pinched plants should be spaced 20 to 24 inches apart in rows 3 feet apart. Pinching also results in continuous harvest over the growing season.

Unpinched plants result in one stem per plant. These plants should be spaced 4 to 5 inches apart. If you are growing unpinched godetia, you will need several sequential sowings to provide cut flowers all summer.

It will take three to four months from sowing seeds to harvesting flowers. Godetia should be harvested when the first flowers on each stem are open.

Lisianthus (*Eustoma grandiflorum*)

Lisianthus should be started from seeds three to five weeks before planting into high tunnels or can be purchased in plug form from specialty propagators.

These plants can also be started from terminal stem cuttings, which are rooted in a clean, lightweight rooting medium. Cuttings will root in about two weeks at 75° F air temperature under intermittent mist or loosely covered with clear plastic.

Lisianthus prefers air temperatures below 65° F for optimum growth and development. Temperatures above 70° F will either delay or completely stop flowering. Because of this, grow lisianthus in the spring or fall, avoiding high summer temperatures.

Young plants should be spaced on 4- to 9-inch centers, depending on the cultivar. Always remove the central flower bud for best-quality stems. The number of weeks from sowing to harvest will be about 16, again depending on the cultivar. Harvest lisianthus when one flower is fully colored, but it does not have to be completely open.

Trachelium (*Trachelium caeruleum*)

Grow trachelium from seeds started four to five weeks before planting into a high tunnel, or buy pre-germinated plugs from a specialty propagator.

Trachelium is another annual that prefers cooler nights like those in Wyoming. Day air temperatures of 60° to 70° F are optimum.

Seedlings should be spaced 9 to 18 inches apart, but planting them farther apart will result in more stems per plant.

First harvest usually occurs about 12 to 16 weeks after sowing, depending on the cultivar. Harvest trachelium stems when one-third to one-half of the flowers are open.

Celosia (*Celosia argentea*)

Celosia, or cockscomb, is typically grown from seeds sown four to six weeks before planting in a high tunnel. Many cultivars can also be purchased in pre-germinated plug form from specialty propagators.

Celosia definitely prefers warmer air temperatures for optimum growth. Day temperatures of about 80° F are recommended. Day air temperatures below 50° F will result in significant delays in flowering.

These plants can be grown either pinched or unpinched. Pinched plants will produce several stems per plant and should be spaced 12 to 18 inches apart. Pinching also results in continuous harvest over the growing season.

Unpinched plants will produce one stem per plant and can be spaced much closer at 6 inches apart. Growing unpinched will require several sequential sowings to provide flowers all summer.

It will usually take about 12 to 16 weeks from sowing to harvest, depending on the cultivar. Harvest celosia when the flowers are fully open (crested types) and 90 to 100 percent open for the plumed types.

Figure 10.3. Brightly colored Celosia is a great summer cut flower.

Amaranth (*Amaranthus caudatus*)

Amaranth is normally grown from seeds sown about three weeks before planting in a high tunnel, or plugs can be purchased from specialty propagators. Air temperatures above 70 F result in faster flowering. Young plants should be spaced 12 inches apart.

It will take about 12 to 16 weeks from sowing to harvest, depending on the cultivar. Harvest amaranth stems when at least three-fourths of the flowers on the inflorescence are open.

Perennial and woody plants can also be used in high tunnels, as well as other bulb crops. However, timing is more difficult, and it generally takes two to three years for most of them to produce many flowering stems.

Resources:

Armitage, Allan M. 2008. *Specialty Cut Flowers: The Production of Annuals, Perennials, Bulbs and Woody Plants for Fresh and Dried Cut Flowers.* Timber Press, Portland, Oregon.

Association of Specialty Cut Flower Growers. http://www.ascfg.org/.

Maree, Johannes and Ben-Erik van Wyk. 2010. *Cut Flowers of the World: A Complete Reference for Growers and Florists.* Timber Press, Portland, Oregon.

Greer, Lane and John Dole. 2009. *Woody Cut Stems for Growers and Florists: Production and Post-Harvest Handling of Branches for Flowers, Fruit, and Foliage.* Timber Press, Portland, Oregon.

Brenzel, Kathleen Norris, Ed. *Sunset Western Garden Book.* 2001. Sunset Publishing Corporation, Menlo Park, California.

11 High Tunnel INSECT and MITE CONTROL

Jeff M. Edwards

If you grow fruit and vegetables in a high tunnel you will eventually have insect or mite problems on your crops. These structures not only protect the plants from the elements but also provide optimal growing conditions for pests. Scouting, correct identification, and understanding the feeding damage and reproductive methods of these pests are key to any good defensive strategy. It is important to understand your control options and have a plan in place to quickly implement tactics that work best for your production strategy.

Integrated Insect and Mite on High tunnel Vegetable Crops

Detection Methods

Pest Detection by Traps

Yellow sticky traps in high tunnels will catch winged aphids, leafminers, thrips, whiteflies, fungus gnats, and shore flies. Blue traps are sometimes better at detecting western flower thrips.

Figure 11.1. Yellow sticky traps are used for monitoring insect populations.

Attach sticky traps to a wooden stake and place the stake vertically in or near a plant at or just above the top of the foliage. This is where most of the "action" is in insect flight activity. Other pests such as fungus gnats, shore flies, thrips, and leafminers can be trapped by placing the sticky trap just above the soil surface. Be sure to place some traps near vents, doors, and other areas where pests may be found. Some growers place traps outside of the high tunnel to help detect insects moving in from outside. The number of traps to use will depend upon your objectives and ability to inspect them. A minimum number should be somewhere around 4-5/acre, but more will be better, especially if using traps to monitor whitefly population trends (1 trap per 1,000 sq ft).

Traps should be visually inspected at least weekly. Captured insects should be identified and counted in order to determine the infestation level. Estimates of pest population density are usually sufficient in order to determine if control measures are needed. Some people prefer to deploy traps for shorter periods; for example, a few hours or a day, to get a better picture of insect activity at that moment. It is a good idea to number the traps and create a map for reference so that all traps can be monitored.

Pest Detection by Plant Inspection

Sticky traps will not replace plant inspection as a pest detection method. Whiteflies occur in localized infestations that traps may not detect. Non-winged aphids and spider mites are not caught on traps. Therefore, plant inspection is a very important part of a pest management program. Inspect plants in all areas of the high tunnel, looking underneath leaves near the top, middle and lower parts of plants. A 10-30X hand lens can be used as an aide in detecting plant pests.

Control Methods

Cultural Control

Destroy crop residues promptly after harvest. The longer these plants remain, the greater the chances are for increased pest problems. It is recommended not to compost plant residue in the high tunnel as it can become a harborage for pest problems. Also, do not place the crop residues immediately outside of the high tunnel; the flying adults from many insect species will simply move back inside. Vegetable gardens planted adjacent to the high tunnel, can also become sources for recurring infestations.

Physical/Mechanical Control

Screens can be useful in reducing the movement of some insects into the high tunnel. Whiteflies, leafminers, Lepidoptera (moths), and winged aphids can be excluded relatively easily. Thrips are very difficult to exclude because of the small screen mesh size required. The use of screens will require increasing the screen surface area over openings in the high tunnel to compensate for reduced air flow. The calculations for surface area increase can be made in cooperation with the screen supplier. High tunnels with mechanical ventilation can be screened more easily than high tunnels with natural ventilation.

Biological Control

Biological control of insects and mites on high tunnel vegetable crops is practiced worldwide. There are beneficial insects and mites available from commercial sources for control of nearly every major insect or mite pest. The most difficult pest to control biologically (chemically as well) is the western flower thrips. Many growers are able to use biological control as their primary

Table 11.1

Commercial Sources of Insect Traps
Great Lakes IPM www.greatlakesipm.com 10220 Church Street, NE Vestaburg, MI 48891 (989) 268-5693
Trece, Inc. www.trece.com (manufacturer of pheromone lures and traps) P.O. Box 6278 Salinas, CA 93912 (408) 758-0204
Gempler's www.gemplers.com/ (general supplier) P.O. Box 270 Belleville, WI 53508 (800) 382-8473
Olson Products Inc. www.olsonproducts.com (manufacturer of sticky card traps) P.O. Box 1043 Medina, OH 44258 (216) 723-3210

Table 11.2

Information Sources Concerning Biological Control
www.cdpr.ca.gov/docs/ipminov/ben_supp/ben_sup2.htm (California Environmental Protection Agency.)
www.anbp.org (Association of Natural Biological Control Producers)
www.nysaes.cornell.edu/ent/biocontrol (Cornell University's site for general information on biological control)
www.ipmlabs.com (Web site of IPM Laboratories, a major supplier of beneficial insects and mites)
www.koppert.nl/e005.shtml (Web site of the Koppert Company, a major supplier of beneficial insects, nematodes and mites)
www.biobest.be (Web site of Biobest Company, a major supplier of beneficial insects, nematodes and mites)

pest management method. Other growers will try to integrate pesticides with few or no harmful effects on beneficials into their program, or apply pesticides only to localized areas where pest infestations are higher than desired. Some growers will use biological controls for part of the year, changing to pesticides if pests become too numerous. Even more than when using pesticides, biological control requires that a good pest scouting and monitoring program be in place.

Integrating Pesticides with Biological Control

Most insecticides are harmful to beneficial insects. These harmful effects can last for weeks following application and should not be used for at least 30 days before beginning a biological control program and do not use them anywhere in the high tunnel after beginning a program. Local or "spot" applications generally are less harmful to natural enemies than treating the entire high tunnel.

Figure 11.2. Insects like aphias can quickly become problems. (Photo: Jeff M. Edwards)

Some registered pesticides are "soft" on beneficial insects and mites. These include: the bacterium *Bacillus thuringiensis* formulations which are harmless to natural enemies. Insecticidal soaps, an insect specific fungus *Beauveria bassiana*, azadirachtin (extract from seeds of the neem

Table 11.3

Some Suppliers of Beneficial Insects and Mites in the United States		
Alternative 349 East 86th Street Suite 259 Indianapolis, IN 46240 (317) 823-0432	**Biotactics, Inc.** www.manta.com/c/mm2fncw/ biotactics 7765 Lakeside Drive Riverside, CA 92509 (909) 320-1366	**Koppert Biological Systems, Inc.** www.koppert.com 28465 Beverly Road Romulus, MI 48174 (800)928-8827 (734) 641-3763
ARBICO www.arbico.com P.O. Box 4247CRB Tucson, AZ 85738 (800) 827-2847	**The Green Spot** 93 Priest Road Nottingham, NH 03290 (603) 942-8925	**Nature's Control** www.naturescontrol.com P.O. Box 35 Medford, OR 97501 (800) 698-6250
Associates Insectary www.associatesinsectary.com P.O. Box 969 Santa Paula, CA 93061 (805) 933-1301	**Hydro-Gardens, Inc.** www.hydro-gardens.com P.O. Box 25845 Colorado Springs, CO 80936 (800) 634-6362	**Planet Natural** www.planetnatural.com P.O. Box 3146 Bozeman, MT 59772 (800) 289-6656
Beneficial Insectary www.insectary.com 245 Oak Run Road Oak Run, CA 96069 (800) 477-3715	**IPM Laboratories, Inc** www.ipmlabs.com P.O. Box 300 Locke, NY 13092 (315) 497-2063	**Rincon-Vitova Insectaries, Inc.** www.rinconvitova.com P.O. Box 1555 Ventura, CA 93002 (800) 248-2847

The above list is for information only. Contact the individual company for information on prices and ability to supply the required biological controls.

tree), and pyrethrum + rotenone tend to be less harmful than conventional materials. This does not mean that these materials are harmless, but that natural enemies can be re-introduced soon after an application without any deleterious effects. Application method and formulation will affect the toxicity, or lack thereof, of pesticides to natural enemies. There are a number of studies that have conflicting information concerning how long a particular pesticide will remain harmful to a natural enemy. When in doubt, be conservative.

The number of registered pesticides for use in Wyoming to control insect and mite pests inside greenhouses (and high tunnels) is highly limited. For greater details concerning the insects found in greenhouse/high tunnel production consult the ATTRA publications concerning control of aphids, whiteflies, or thrips. These publications can be found at the following web locations:

- www.attra.org/attra-pub/gh-aphid.html
- www.attra.org/attra-pub/gh-whitefly.html
- attra.ncat.org/attra-pub/gh-thrips.html

Table 11.4

Commercially Available Biological Control Agents		
Common Name	**Scientific Name**	**Pests Attacked**
Whitefly parasitoid	*Encarsia formosa*	Whiteflies, especially the greenhouse whitefly
Whitefly predator	*Amblyseius swirskii*	Whiteflies, greenhouse and silverleaf whitefly, also attacks thrips
Leaf miner parasitoids	*Diglyphus* spp., *Dacnusa* spp.	Leafminers
Aphid midge	*Aphidoletes aphidimyza*	Aphids
Aphid parasitoid	*Aphidius colemani*	Green peach and melon aphids
Aphid parasitoid	*Aphidius ervi, Aphelinus abdomalis*	Potato aphids
Soil insects predator	*Atheta coriaria*	Fungus gnat larvae, shore fly larvae, western flower thrips pupae
Entomopathogenic nematodes for fungus gnats	*Steinernema feltiae*, plus others	Fungus gnat larvae
Fungus gnat and thrips predatory mite	*Hypoaspis miles*	Fungus gnat larvae, thrips prepupae (Also: shore fly larvae)
Spider mite predator	*Phytoseiulus persimilis, other phytoseiids Amblyseius californicus*	Spider mites
Green lacewings	*Chrysoperla* sp.	Aphids, whiteflies, mites, caterpillars
Minute pirate bug	*Onus insidiosus*	Thrips, other pests
Thrips predator	*Neoseiulus cucumeris, Amblyseius degenerans Amblyseius cucumeris*	Thrips
Moth parasitoid	*Trichogramma brassicae*	Moth eggs

12 DISEASE PROBLEMS in High Tunnels and their management

Karen Panter

Disease management in high tunnels is best approached using integrated pest management (IPM) strategies.

These strategies include physical methods (such as screening to keep out insect vectors), cultural methods (such as changing irrigation or fertilization levels), biological methods (such as using antagonistic diseases), and chemical methods (such as fungicides). The foundation of an IPM program is regular scouting and monitoring. At least twice a week, check representative plants in each high tunnel for potential disease problems. If there are numerous plant types being grown, each type should be checked. Look for abnormalities on upper and lower leaf surfaces. Catching disease problems early can help prevent an epidemic.

Prevention is another IPM component to minimize disease issues. Growers can do this by using:

- clean soil or growing media.
- clean, bagged seed germination media from a reputable producer for starting seeds.
- insect- and disease-free plants. Inspect them when you receive them and isolate new plants for a few days to make sure they do not develop any diseases.
- certified disease-free seeds.
- clean tools in the high tunnel. Make sure hoes, shovels, trowels, etc., are disinfested after each use to minimize spread of pathogens. If multiple high tunnels are in production, clean tools between tunnels to minimize spread of insects and diseases.
- crop rotation within a tunnel or among tunnels each growing season to minimize disease problems.

Lastly, growing plant varieties bred with resistance to pathogens is an excellent prevention strategy. Many tomatoes, for example, have resistance to *Verticillium*, *Fusarium*, or nematodes built in.

There are two major groups of diseases that affect horticultural crops in high tunnels: soilborne and foliar. Following are examples of each and some methods to minimize crop losses.

Soilborne Diseases

The most common soilborne fungal pathogens affecting horticultural crops in Wyoming include *Pythium*, *Rhizoctonia*, *Verticillium*, and *Fusarium*. *Pythium* and *Rhizoctonia* attack root systems, slowing or stopping water and nutrient uptake. *Pythium* infections start at root tips and advance toward the crown of the plant. *Rhizoctonia* starts at the crown of the plant and moves downward through the roots. *Fusarium* and *Verticillium* clog the vascular systems of plants, stopping water flow from the roots to the upper parts of the plants and causing irreversible wilt. All of these pathogens persist in infested soil and plant debris and are easily moved from plant to plant by splashing water, tools, shoes, and hands.

Minimize the effects of soilborne pathogens by sowing seeds and establishing transplants in a clean, bagged, soilless mix or media treated with biofungicides. These biofungicides often are beneficial microflora. In addition, avoid overwatering, which often favors soilborne pathogens. Use irrigation strategies that minimize splashing soil and water. Rotate crops within the tunnel or in other tunnels. All these strategies can help keep soilborne diseases at bay in high tunnels.

Foliar Diseases

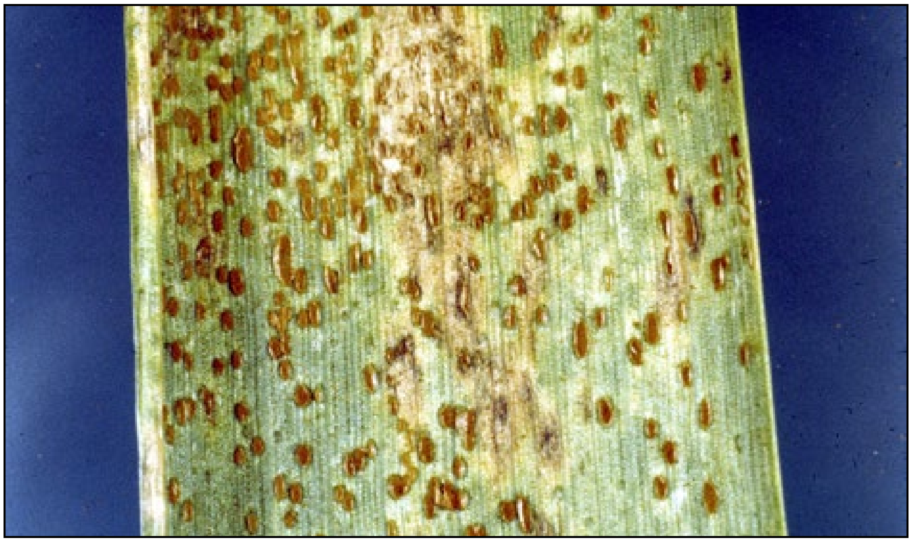


Figure 12.1. Puccinia rusts (Photo: Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org)

One of the most common foliar diseases is powdery mildew, which is seen as white, powdery growth (mycelium) on leaves. Powdery mildew fungi, found on an enormous array of host plants, require humidity to grow and spread. Standing water, however, is lethal to the spores. Increasing air circulation helps in management of powdery mildew. In a high tunnel, this means rolling up the side vents when the weather is warm enough or opening the door(s) if no side vents are available. Also, giving plants adequate space is critical in minimizing most foliar diseases, including powdery mildew. Close spacings invite disease problems. Neem-based fungicides (neem is a botanically derived pesticide), bicarbonate-based fungicides, and biofungicides such as *Ampelomyces quisqualis* and *Bacillus subtilis* help minimize the effects of these diseases.

Other foliar diseases include those caused by fungi, bacteria, and viruses. Bacterial and viral diseases are very difficult to manage. Often, the best remedy is simply to remove the affected plants.

Three other fungal foliar diseases that may be encountered in high tunnels are *Botrytis* (gray mold), *Alternaria*, and *Puccinia* (rust). Gray mold attacks almost any type of plant, favoring flowers. It thrives in high humidity, so increasing air circulation in the high tunnel will help prevent infections. *Alternaria* causes leaf spotting and is typically seed-borne. It will attack young seedlings as a result. *Alternaria* species are host-specific, so transfer of the pathogen from one type of plant to another is usually not a problem. Rust is usually easily seen, as it produces yellow-orange or brown pustules on upper leaf surfaces. Some horticultural crops are very susceptible to rust, including chrysanthemums, geraniums, and snapdragons. Rust species are also very host-specific, but they can build up quickly under conditions of high humidity.

Bacteria can also cause major disease problems on plants in high tunnels and most are very host-specific. One of the most damaging is *Xanthomonas*. One species, *Xanthomonas campestris* pv. *pelargonii*, favors geraniums. Bacteria cause necrotic (brown) lesions that are small and round and sometimes surrounded by a yellow halo. Necrotic lesions may expand to wedges on the leaves. Bacterial diseases in general are favored by warm, humid conditions. Increasing

Figure 12.2. Bacterial Blight on Geranium caused by *Xanthomonas campestris* pv. *pelargonii*. (Photo: Cornell University Extension)

air circulation within the high tunnel and keeping foliage dry will help keep these diseases at bay.

Some of the hardest pathogens to manage in high tunnels, or any type of production system, are viruses. Tospoviruses are some of the most damaging to horticultural crops. Two types of tospoviruses, impatiens necrotic spot virus (INSV) and tomato spotted wilt virus (TSWV), have a very large host range. These viruses are transmitted by the western flower thrips. The best way to manage the viruses is to control thrips. Both INSV and TSWV cause stunting, spots, concentric rings, stem cankers, or wilt. The only way to determine if these viruses are causing these symptoms is to have a plant disease diagnostic lab run an ELISA test (enzyme-linked immunosorbent assay) on symptomatic plant tissue.

Proper management of all diseases hinges on proper diagnosis. Diagnosing plant problems is best left to a university extension specialist or consulting professional who works with a plant diagnostic laboratory. Symptoms of many plant diseases are similar. Some diseases must be cultured (grown in an artificial medium) in a lab to make a definitive diagnosis.

With proper diagnosis, the grower can then work with extension or a consultant to determine the appropriate management actions, which may include a fungicide application.

Figure 12.3. Tomato spotted wilt virus
(Photo: Iowa State University Extension and Outreach)

Figure 12.4. Impatiens necrotic spot virus
(Photo: Mary Ann Hansen, Virginia Polytechnic Institute and State University, Bugwood.org)

13 FREQUENTLY ASKED QUESTIONS concerning High Tunnels and production

Jeff M. Edwards

Style and Economics of High Tunnels to consider:

What is the best design for a high tunnel?

This depends upon your budget, need as a producer, and space available for a structure. There are basically two styles: a straight hoop, or gothic. These designs similarly shed the wind. However because of the gothic style roof angle it appears that light quality is diminished late fall through early spring (so orientation becomes a factor) and this style does not shed snow well.

What is the best size?

This depends on what you are attempting to accomplish with your high tunnel. Commercial producers will look for a size that can maximize production - for example a 30-ft X 96-ft, whereas a backyard grower may only have room for a 12-ft X 12-ft. Research suggests that the larger the air mass inside a high tunnel the more stable the temperature. Data available also suggests that the length and width maintain a 2:1 ratio for optimal temperature management. One may also consider the possibility of multiple smaller structures and dedicate each one to a specific crop and rotate crops between structures and seasons to help reduce insect and disease pressure.

Height considerations:

Wyoming is a windy environment you should be aware that for every foot increase in height there is a 4x increase in wind resistance –you may only need tall enough to walk into vs. tall enough to drive farm equipment into – brace and support the ends to support the potential wind load.

What about kits I see on-line?

A perfectly viable option – there are producers in Wyoming who have constructed and are using them. Do your homework, they can be pricey.

Some kits use either zipper or Velcro™ closures for the door ends. ***These will not hold up in Wyoming wind***. Either frame in a standard size door or build your own custom-sized door. Solid end walls are not required, but may be useful in highly windy environments.

What options are available for smaller scale producers?

UW Extension has been conducting educational workshops around Wyoming that show participants how to build their own high tunnels. The designs used have been adopted and modified from structures created by Del Jimenez at New Mexico State University. These structures are built using locally available materials (excluding the woven poly "skin"). Material and resource lists are available at the following:
http://www.wyomingextension.org/whhin

What is the minimum number of people needed to build one of these structures?

Two for the framing construction portion, four for skinning the structure on a calm day…more will be needed if the wind is blowing.

What are desirable additional systems that make operating a high tunnel better at retaining heat?

There are limited data available on heat sink usage in high tunnels. Heat sinks can be as simple as a row of black barrels filled with water, cinderblocks painted black or more elaborate Trombe wall systems, (a Trombe wall is a south-facing wall separated from the outdoors by an air space, which absorbs solar energy and releases it selectively towards the interior at night) any structure that can capture radiant heat during the day and give it off at night will increase the number of days for viable production. Additional tactics include double skinning the structure and/or adding an insulation barrier to the perimeter around the structure. A demonstration of these tactics was initiated in Laramie in 2012.

Materials

What is the expected lifespan of this type of structure?

This depends on how well it is maintained. Wind, hail, snow, and UV light are the primary causes of material failure. If there are rips in the "skin" material, they will need to be patched or the skin replaced. If snow does not slide off the top easily, one will need to remove it or brace the ribs inside. UV light will degrade the quality of the skin material. One of the manufacturers of the woven poly material claims that the skin will last 1-year per mil of thickness (i.e., a 6-mil product should last 6-years).

What is the best way to anchor the high tunnel to the ground?

Use "batten tape" over the top of the tunnel between the rib spaces to keep the skin material from fluttering in the wind. Tears will occur in the skin material where rub points occur. Anchor the structure to the ground by burying excess skin material in the soil around the perimeter and using material straps (in addition to the batten tape) over the top,. Also and most importantly bury the door frame posts a minimum of 2-feet into the ground and add anchors to in the inside base with at least 2-foot long rebar "pins".

Orientation

Which is the best way to orient the structure?

The data suggest orientation North to South for structures North of the 40th Parallel (and planted north to south so that as the sun tracks from east to west the light will be able to get to all plants and through the canopy between the rows) if the plants are in rows east to west there is the possibility of shading from row to row – this affect is exaggerated after the autumnal equinox. This orientation is only a consideration if using standard greenhouse skin material, orientation is not a light consideration if using the woven polyethylene skin material. The light is diffused as it passes through the skin material and as it bounces around the inside of the structure it reaches all areas of the plants equally. When using the polyethylene skin the primary consideration for orientation will be the direction of the prevailing wind and the ability to ventilate the structure.

Figure 13.1. Crop production in high tunnels is on the increase. (Photo: Sandra Frost)

Ventilation

What do the roll-up sides do and why might I need to prop open the doors?

In Wyoming High Tunnels are used as a means to extend either end of the growing season. Production can continue inside them through the heat of the summer. The roll-up sides and doors are used to ventilate and allow air flow through the structure to prevent overheating.

What is the “trigger point” for rolling up the sides or propping the doors open?

Local data suggests that the temperature inside the structure can exceed 100 degrees F, when the outside air temperature passes 50 degrees F. If the daytime temperature is expected to be above 50 degrees be prepared to open and ventilate the structure.

What is the “trigger point” for rolling down the sides or securing the doors?

At any point where the temperature is expected to be near freezing (32 degrees F) the structure should be closed.

What do I do with the sides and/doors if the wind is going to blow?

Either leave them secured completely open and allow the wind to blow through or completely close the structure. Wind is the number one cause of material failure for these structures.

General Comment concerning rollup sides and doors:

Roll up sides and doors only need to be managed (opened or closed) during transitional weather periods (Spring and Fall) otherwise they should remain open in the summer (to vent) and closed in the winter (to retain as much heat as possible).

How much time/labor is involved in ventilation management?

The best answer is “minimal”. What is involved in ventilation management is enough time to check the weather and decide if the structure will need to be ventilated, then enough time to open or close the structure as needed.

Production

How early in the spring can I plant?

This truly depends on a variety of conditions – particularly the soil and the night time ambient air temperatures. The easiest way to determine the proper planting time is to plant a moderately cold tolerant crop (i.e., spinach) in February. When the spinach germinates; the soil is warm enough and it is time to begin planting other crops.

Raised beds

Should I build raised beds?

Only if your soil is poor or if you have limited mobility – the protected area inside the high tunnel is the greatest commodity for your investment – grow on as much space as possible.

What can I use for raised beds?

Anything – but recognize that materials have life spans and different cost associated with them. Stone and brick will last the longest. Plastic (may not be a good choice) and lumber (pressure treated should probably not be used unless lined with an inert product) will need to be replaced more often. There are biocomposite (recycled plastic + organic fiber) materials available that also make good raised beds.

How tall should I make the side walls for my raised beds?

This is entirely up to you. Things to consider: your own mobility, the crops you are going to raise, the materials you are going to use, your budget, how much soil are you willing to move. Deep rooted crops (i.e., sweet potatoes, turnip, carrots, & parsnips) could use about 18” beds. If your mobility is a consideration, a raised planting “table” could be used – but must be reinforced to withstand the weight of the soil water and crops being grown. Also remember that you must move all the soil into a raised bed (on average one cubic foot of soil is about 78 pounds). A 10-foot X 3-foot X 18-inch bed will need about 45 cubic feet of soil = about 1.5 to 2+ tons depending on the soil type and moisture content.

Crops

What can I grow?

High tunnels with one layer of poly-skin material are capable of increasing your USDA growth zone by one (i.e., normal USDA growth Zone = 4, plus one poly-skin layer will extend the growth zone inside the high tunnel to USDA growth Zone 5) and even in Wyoming it is possible to gain two USDA growth zones – with 2x poly layers. Focus on the crops you may have difficulty with in your garden: Tomatoes, peppers, melons or fruit. High Tunnels will also allow you to grow leafy greens and other cool season vegetables earlier in the spring and later into the fall. Most of all experiment – if there is a crop you are interested in and the number of relative days to maturity is less than 150 – try it you may be surprised.

Specific Comments about Tomatoes:

Determinate vs. Indeterminate – Determinate plants (also known as "bush type") grow to a point flower and produce fruit and stop growing – they will have fewer days to achieve relative maturity. Indeterminate plants (also known as "vine type") continue to grow, flower and produce fruit until the growing conditions (day length is too short or temperature is too cold) are no longer favorable. Indeterminate plants if started in March can continue to grow until November (in certain areas of the state) these plants could be potentially 14-16 feet tall by the end of the season and will need to be supported - extensively.

Other Items to consider:

There are no rules set in stone, you will have a learning curve concerning how to best manage your structure…most of all have a long productive growing seasons!

Figure 13.2. Sunflowers, tomatoes, and daisies can all be grown successfully in high tunnels.
(Photo: Karen Panter)