Hoophouse Environment Management:
Light, Temperature, Ventilation

John Biernbaum, MSU Horticulture

Materials and Readings:

Winter Harvest Manual: pgs 33-74
High Tunnels: pgs 47-52
Four Season Harvest: pgs 104-130
Hoophouse Handbook: pgs 25-29

Background and Perspective

The atmospheric or above ground environment is characterized by the amount of light, the temperature, the moisture in the air or relative humidity, and the amount of carbon dioxide in the air. There are both similarities and differences between managing a greenhouse and a hoophouse or high tunnel which are not heated.

Light Management:

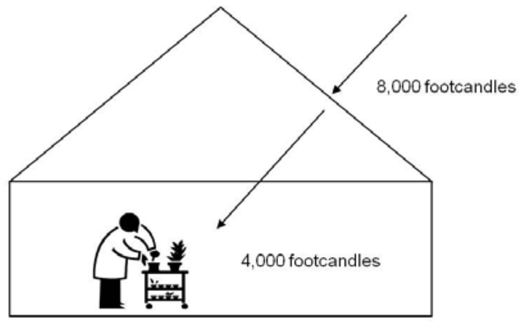
As we look at some of the details of light and temperature management, we will see that in the summer there is generally an excess of light for adequate plant growth and yield as long as plant spacing is adequate, and that keeping temperatures in the greenhouse cool will be a key management strategy. For winter production and harvesting for latitudes above 40^o latitude, maximizing light is going to be important. Without clouds, there generally is enough light for plant growth, but light also is a primary factor influencing both day and night temperature in the greenhouse.

Light intensity is often measured or reported in either “footcandles” or “micromoles”. Examples of a range of light intensities are provided in the table below.

Situation or Condition	**Footcandles**	**umol/m^2*second**
Full summer sun in Michigan	10,000	2000
Cloudy winter day in Michigan	Less than 1000	Less than 200
Bright moon lit night	Less than 2	Less than 1
Greenhouse high light	5000 to 6000	1000 to 1200
Greenhouse moderate light	2000 to 4000	400 to 800
Greenhouse low light	Less than 2000	Less than 400
6” from fluorescent lamp	300 to 400	60 to 100
5’ from 400W HID, HPS, or MH lamp	300 to 400	60 to 100
Classroom or office lighting	50 to 100?	10 to 20

The hoophouse structure and covering will determine the overall light transmission and intensity. The intensity in the greenhouse at crop height should be over 65% and as much as 80% of the intensity outside the greenhouse (percent light transmission = (inside)/outside).

Light transmittance for a double polyethylene greenhouse can be in the range of 60 to75% at crop level compared to outside. When interior levels get to the 50 to 60% of outside, the film probably needs to be replaced.

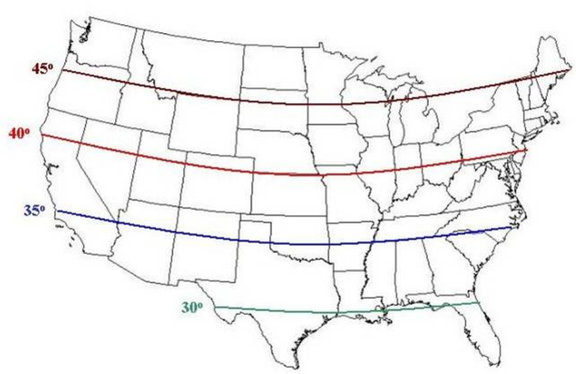


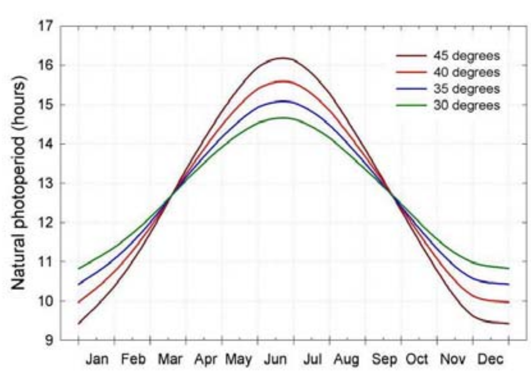
$$\text{Percent transmittance} = \frac{\text{Amount of light passing through}}{\text{Amount of light at the surface}} \times 100$$

$$\frac{4{,}000 \text{ footcandles}}{8{,}000 \text{ footcandles}} \times 100 = 50 \text{ percent transmittance}$$

Plastic / polyethylene greenhouse plastic film light transmission will decrease over a period of years. Measuring light transmission is one of the best ways of testing when to replace the film.

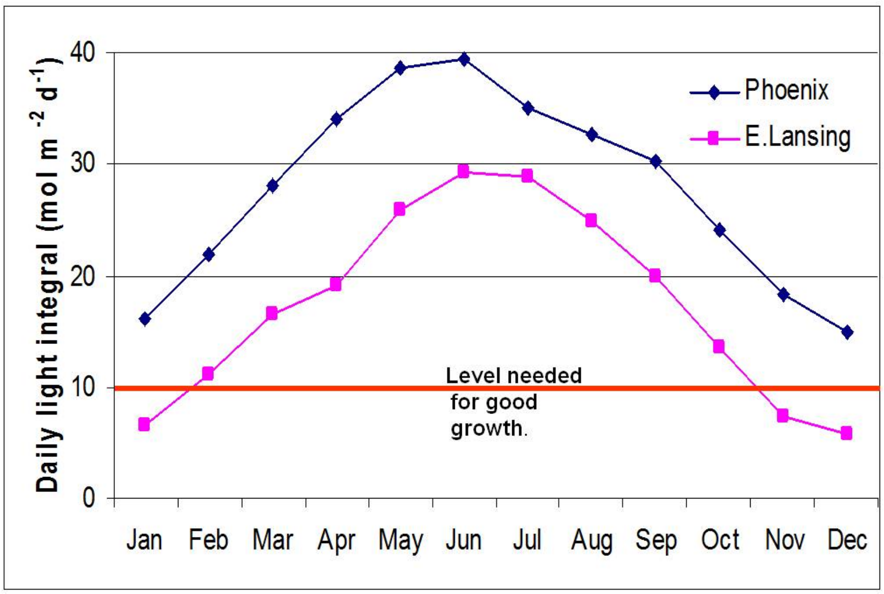
At our latitude in Michigan (about 41^{o}N) the day length ranges from about 9 hrs on Dec 21 to around 16 hours on June 21. Does this mean there is about half the light in December that there is in June? No, because in addition to decreasing day length, during the winter the intensity of light is also decreasing dramatically. How much does the light change seasonally?





To answer this question, we need to first understand that the amount of light available for plant growth is a result of the day length and the light intensity. For example, if we have plants in a room and turn on a light for 12 hrs at 250 footcandles (intensity), we could get similar plant growth if the light was on for only 6 hours at 500 footcandles or 24 hrs at 125 footcandles.

In our hoophouse, light intensity of course changes from sunrise to sunset. If we measure how much light there is each second and add it up all day, we get a unit of measure that includes both time and intensity. For plant growth in greenhouses, this unit is called the daily light integral (DLI) and has units of sunlight energy per unit of area and day or unit time - mols per square meter per day (or per second). The DLI can range from as low as 2.5 mol/day to as much as 50 moles/day – a factor of 20. That means there might only be 5% of the light on a cloudy December day that there is on a sunny day in late June. We can easily say the difference is at least 10 times the amount and not one half or one quarter. Battery operated equipment to measure the DLI is available for about $450 (www.spectrum.com) but is not necessary. We use one in our research to help identify differences.



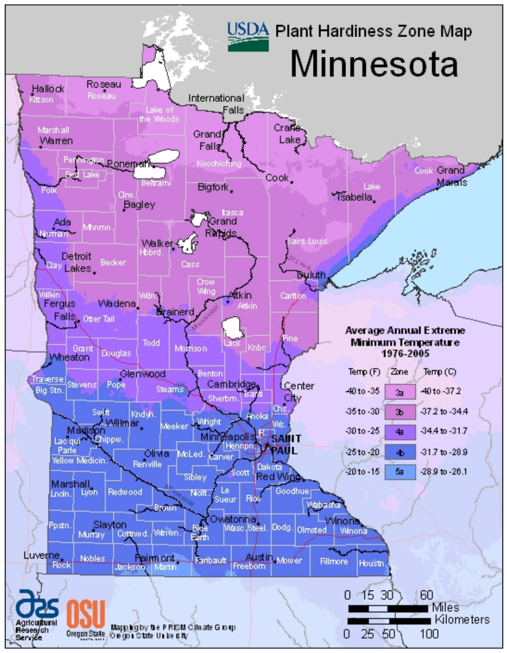
From greenhouse flower production research, we know that when the DLI drops below 10 for the day, that plant growth slows considerably. We also know that the outside light level drops to this point or lower in December and January in Michigan. When we take into account that the greenhouse covering can reduce the light by 60 to 70%, we begin to understand why plants do not grow much in December and January.

Before we switch to talking about temperature, we should note that based on our previous discussion, there is plenty of extra light for plant growth in the summer. This extra light tends to heat up the greenhouse but obviously does not hurt the plant. For most crops, except cool climate leafy green crops like lettuce, we do not need to provide any shade in the summer.

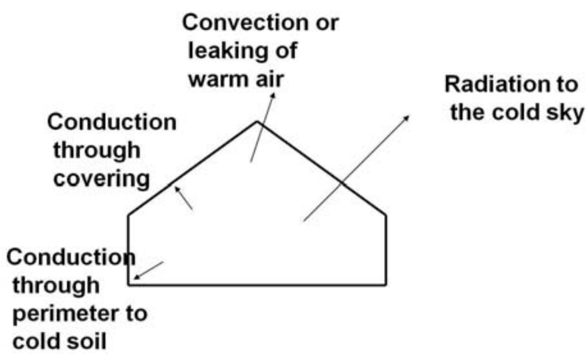
There is enough light in the northern US to grow leafy greens in the winter if temperatures are maintained in the 45 to 55 degree F range. A reason to suggest that light is limiting in the winter hoophouse has more to do with the fact that in a passive solar greenhouse, the light determines the temperature and the temperature determines the growth.

Temperature Management:

Plant hardiness or heat zones have been defined that give an indication of average temperature conditions.



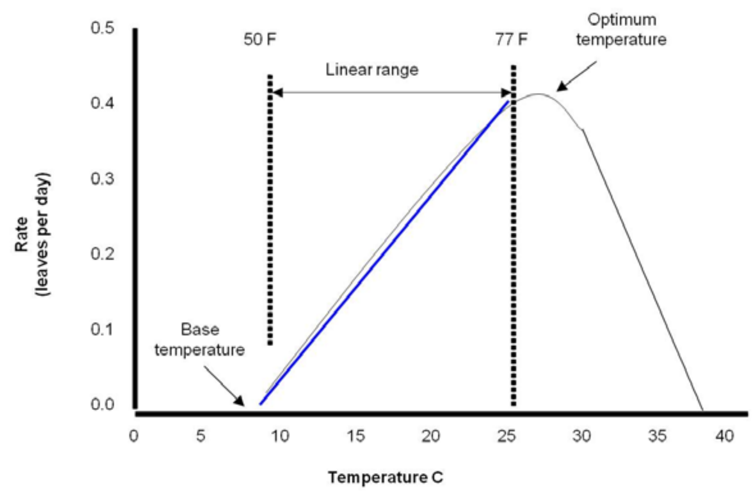
Heat loss from a greenhouse occurs in three main ways.



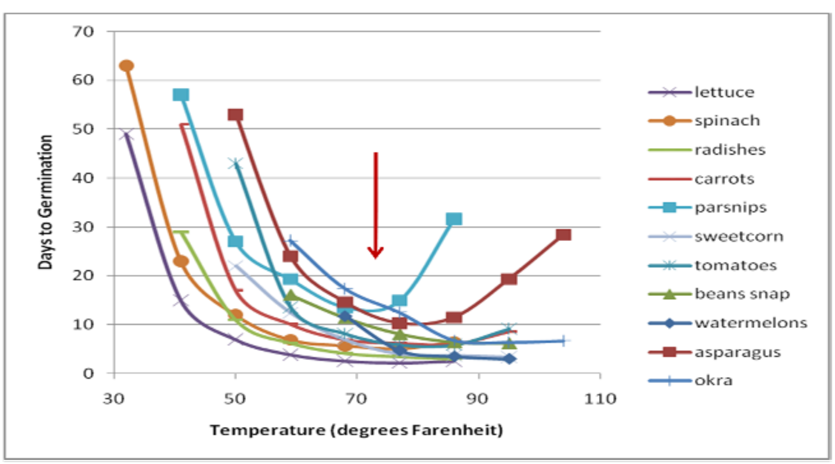
For a heated greenhouse the primary heat loss is by conductive heat loss through the covering. For an unheated hoophouse or passive solar greenhouse, the primary heat loss is through radiant heat loss. When is it warmer? On a clear night or a cloudy night? Most people understand that on a cloudy night the moisture in the atmosphere reflects radiant heat from the earth back to the earth. In a passive solar greenhouse at night, radiant heat from the soil is trapped when moisture condenses and or freezes on the plastic film covering of the greenhouse and any internal tents.

Just as the total amount of light over the day or DLI is a good predictor of the amount of plant growth, the *average daily temperature* or ADT is also a good predictor of the amount of plant growth. However, we also need to take into account that most warm season plants like tomatoes or melons do not grow very much at all if the temperature get down to 50 or 55F. We call the temperature where growth is minimal or stopped the *base temperature.*

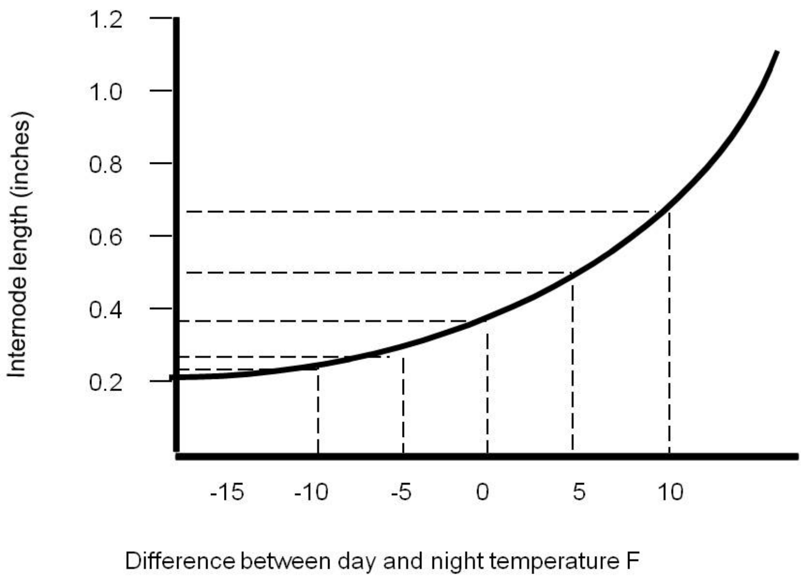
For cool season crops like spinach, the base temperature, where there is little or no growth, is in the range of 32 to 35F. As the average daily temperature increases above the base temperature, in general plants grow proportionally more until the temperature optimum, which is around 75-77F is reached. For example, if the range from base temperature to optimum temperature is 50F to 75F (25 degrees difference), for a 5^{o} F increase in ADT, the plants would grow about 20% (5 divided by 25 = 0.20 or 20%) faster.



The following illustration is an example of how seed germination of several species is influenced by soil temperature. The fastest germination for a range of species occurs around 70 to 75 degrees F. For comparison to the graph above, 25 degrees Celsius is about 77 degrees F.



Another important aspect of how plants grow in response to temperature is that the relationship of day temperature to night temperature influences the height of plants by influencing the stem length between leaves or the “internode” stem length (the distance between two leaf nodes). As the difference or DIF between the day temperature and the night temperature increases (a more positive DIF), stem length generally increases. As the difference or DIF decreases, stem length decreases. In heated greenhouses the night temperature can be set warmer than the day temperature so there is a negative DIF and plant stems can be even shorter.



Where this might be important for PSGH operators is that allowing the greenhouse to get very warm during the day and then very cool or cold at night will likely result in longer internode lengths than will be seen in field conditions. This can be an advantage when growing cut flowers where stem length is valued. It may also influence fruiting crops such as tomato, pepper and eggplant where a more open plant canopy may have an advantage to increasing light interception.

Soil temperature can also influence plant growth. For plants growing in containers in heated greenhouses, soil temperature usually follows air temperature in a predictable fashion. When growing in unheated greenhouses in the native soil, soil temperature will be influenced by the amount of sunlight, the amount of soil moisture, and the air temperature. If the soil does freeze, it is difficult for plants to take up water when the sun comes out bright and the soil has not thawed. For winter growing, soil temperature is one indicator of the energy or temperature in the greenhouse.

Interior row covers with frost protection fabric increase temperatures significantly. In the greenhouse, there usually are not problems related to wind blowing and moving the covers. When the air temperature decreases, moisture from the air condenses on the fabric. As explained previously, the moisture helps to trap long wave radiant energy emitted by the soil or plants. Ice forming on the covers and the plastic helps trap heat. We call this the cloud or igloo effect. We have examples of temperature outside being from 0 to -20F while temperatures under the cover inside the greenhouse have rarely gone below 12-15F. Most of what we grow survives at this temperature. Lettuce will survive but top growth is damaged, usually once air temperature under the cover goes below 20 to 25F.

Opening the covers in the morning on sunny days to allow the sun to warm the soil can help increase temperatures under the fabric when it is pulled over the crops at the end of the day. Following warm days, it is important that fabric covers are pulled back into place before air temperature approach freezing or the damp fabric will freeze together and tear when pulled apart. Under very cold conditions, some growers will apply a second layer of fabric at night.

One way to estimate the effect of night time low temperatures is to use buckets of water placed in strategic locations. In my experience, a five gallon bucket half full with water will form ice if in the greenhouse but not under the interior tent while a bucket under the interior tent will not form ice.   Some farmers place cups of water under either single, double or triple cover or dry or moist cover and were able to estimate the cold exposure for each treatment by measuring how much ice formed, actually by measuring the amount of non-frozen water. More layers and moist covers provided more protection.

In the summer, temperatures can reach 100+F. Usually temperatures are reduced by ventilation (roll up sides) rather than shading. For summer lettuce production, the tunnel could be used as a shade structure. There is some question about just how limiting the high temperatures are to warm season crops. High temperatures may not be limiting or as limiting if soil moisture is maintained at high levels.

The negative impact of high PSGH temperature (>85^{o}F) is often on flower viability and fruit set of crops like tomatoes, peppers and eggplant. Loss of fruit set can be very damaging to harvests and income. Monitor plants regularly so if signs of poor fruit set are visible that steps can be taken such as more ventilation, adding shade, or using evaporative cooling.

It is important to note how geographic location can have a large effect on summer day time high temperatures in a PSGH. In Michigan excessive summer greenhouse temperatures at the MSU-SOF have been a problem in one of the last 10 years. But in the areas to the south high summer temperatures have been a much larger problem.

The key to reducing day time high temperatures is usually increased ventilation. If that does not work, in some cases shade fabric is necessary to reduce temperatures.

Temperature Range Examples

Condition	**Fahrenheit**	**Celsius**
Winter lows for zone 5	-20	
ADT for coldest month (Lansing)	14	
Cold tolerant crops in PSGH damaged	<15	
Water freezes	32	0
Cool season crops stop growing	35	
	40	4.4
	50	10
Warm season crops stop growing	55	
	60	15
Optimum ADT for cool season crops	65-70	
	70	21
Optimum ADT for warm season crops	75-77	25
Upper ADT limit for plant growth	90	32
Upper peak limit for plant growth	105-110	
Water boils	212	100

Each rise in degree in F is approximately 1.8 degree rise in C.

- Conversion formulas: T(F)= 9/5 x T(C) + 32 or T(C)= [T(F)-32] x 5/9

Shade Fabric

If shade is used, the most common type used is one that reduces light by 50% (ie 50% shade of light transmission). This reduction might be used for leafy greens. For summer fruiting crops, 30 or 40% shade is a better starting recommendation.

Applying the shade outside the hoophouse reduces the heat load in the greenhouse. For commercial greenhouses, a frame is sometimes constructed about the structure so the shade fabric is not in contact with the polyethylene roof and to allow easy removal of the shade when it is not needed.

Ventilation

The air in a greenhouse or hoophouse is exchanged for either the purpose of 1) introducing fresh air to provide carbon dioxide needed by the plants, 2) exhausting warm moist air to reduce the relative humidity, or 3) for cooling the greenhouse.

In a heated greenhouse full of potted or container grown plants, carbon dioxide can become limiting on a bright cold winter day. In a hoophouse with plants grown in soil, preferably with a high organic matter content (greater than 4 percent), carbon dioxide from microbes in the soil will likely provide adequate carbon dioxide for plant photosynthesis.

Summer Ventilation

In the summer, the goal is to use passive ventilation as to avoid the cost of electricity used to power large exhaust fans common for commercial greenhouses. Roll up sides and or large end wall doors are the most common forms of ventilation. Ridge vents common in commercial greenhouses are not used in hoophouses primarily due to the significant additional cost compared to roll up sides.

Excess air temperature, usually over 90 to 95^{o}F, can reduce growth of some crops. Usually the greatest concern in a hoophouse is the effect of high temperature on pollination and fruit set of warm season summer fruiting crops such as tomato, pepper, eggplant and cucurbits. When temperatures are exceeding 95^{o}F for several house during the day, if increased ventilation does not reduce the temperature, the use of a shade fabric on the roof or the introduction of evaporative cooling using a mist of water will likely reduce the temperature to an acceptable level.

Winter Ventilation

High relative humidity or excess moisture in the air can lead to condensation on the room which reduces light transmission and more importantly conditions that favor development of foliar plant diseases. The tighter the hoophouse – ie the less draft or leakage of cold air, the greater the chance of excess moisture in the winter. Ventilation of warm moist air may be necessary on sunny days. In the winter only a small vent is needed. End wall louvered or butterfly peak vents are most common.

Another concern in the winter is the effect of high day temperatures on the cold hardiness of the plants at night. Some farmers let the house heat up in an effort to gather heat for the night. Other farmers prefer not to let the day temperature get more than 40 oF above the anticipated low night temperature. For example, if a low of 0^{o}F is anticipated, the hoophouse would not be allowed to warm over 40^{o}F the preceding day.

Passive Solar Greenhouse Growing: Winter Light and Temperature Management

Entering the fall season, the day length and light intensity are decreasing and the earth and soil are cooling. At 40^{o}N latitude, we are decreasing from 16 hours of daylight in June to 9 hours in late December. The moles/day of energy are decreasing from as much as 50 to 2.5 or less – a 20 fold difference (Dec 21 may be 5% of June 21.).

The hightunnel and plastic film trap heat during the day and the warmer air helps warm the soil. The sun also warms the soil. The warmer the soil, the more energy (heat) is radiated back out into the surrounding air at night so the soil becomes a source of heat. Heat is lost either by conduction (heat movement through a solid), convection (heat movement by air movement) or by radiation. In a heated greenhouse, conductive loss is most important, followed by convective leaking of warm air, and radiant heat loss is considered very small. For an unheated high tunnel, long wave radiant heat loss becomes very important, convective leaking of warm air is second, and conductive heat loss is considered small.

Polyethylene film is transparent to long wave radiant heat energy so the warmth is lost like on a clear night with no clouds. The frost fabric acts like a layer of clouds and helps hold in and capture radiant heat. Since water reflects radiant energy, any moisture that accumulates on the fabric, either as a liquid or frozen, helps trap heat and radiant energy creating a cloud or "igloo effect".

However, because the frost fabric only has 85% light transmission or less, it reduces the amount of energy getting to the plants and particularly the soil on sunny days. It is wise to pull it back and expose the soil and plants on sunny days. Not only do the plants need the full sun, it serves to better heat the soil. You can think of it as "recharging" the soil. In addition, we want to avoid "cooking" our plants by creating too much warmth and moisture under the fabric. Our hightunnels are at a research farm several miles from the middle of campus so we typically were not there every day in the first two years of research. Our plots stayed covered for long periods of time and performed reasonably well. Crops should do better and soil temperatures run warmer with the soil uncovered on sunny days.

More layers of fabric or heavier fabric can help maintain higher night temperatures due to more insulation. But, if not removed during the day, temperatures will decrease over time due to less sunlight getting to the ground. Under temperature conditions >15^{o}F outdoor night temperatures, the extra layer may be more work then benefit. If temperatures are to be extremely low and important crops need to be protected, extra layers or heavier fabrics are likely justified, but are best removed during the day when temperatures increase.

We have some beds covered with 6 mil polyethylene greenhouse film. Plastic film is generally easier for us to manage than the frost fabric. With film the temperature and the moisture level under the cover can be higher than with fabric.

Our high tunnels are not perfectly sealed. We tell ourselves and others that this is because the air leakage helps keep the relative humidity down and condensation reduced. This conclusion is influenced by the fact that we are not always on site and able to ventilate the houses midday. A preferred strategy would be to have the houses sealed up tightly to conserve heat at night (reduce convective cooling), and then to have vents to ventilate the tunnel midday or later in the day when moisture accumulates or begins to condense. Well sealed, double layer inflated tunnels are essential if minimal heating is being used.

Ten Guidelines for Managing Tunnel Air and Soil Temperature:

#1 Know your weather forecast. The information is essential for decision making. Check the daily forecast before reporting for work for the daily decision making and check the long range forecast to anticipate upcoming low temperatures and cloudy weather. While the reports can be wrong about cloud cover and precipitation, there is pretty good accuracy about night time lows.

#2 Fabric must be pulled over the plants when temperatures are predicted to go below 35ºF for the night. Early in the fall when the soil is still warm there is a little more flexibility than in the winter when the soil has cooled. The air temperatures at our farm will often run *at least* 5ºF below what is predicted for the city of Lansing. It helps to know how your farm and the surrounding area differ due to changes in elevation or density of structures.

#3 Uncover on sunny days unless there is no one available to recover in the evening such as on Sundays. Recover plants before sundown *or* if there is a dramatic change in the weather. Watch for changes in wind speed and direction. During December and January, at our farm hightunnel temperatures peak around 1:30 to 2:30 and begin dropping quickly by 4:30. The frost fabric is usually wet and will freeze together making it very difficult if not impossible to stretch over the plants. Don't let pulled fabric freeze together!

#4 Pull the fabric/plastic so that it is stretched over the supporting wicket, water pipe or conduit framework. If the wet fabric is touching the foliage and freezes, damage to the foliage will likely occur. These damaged areas of foliage are then more susceptible to a pathogen infection. You will also find that excess moisture that collects on the fabric will cause it to sag downward towards the plants. Keep this in mind as you tighten things down with clothes pins. Shake off excess accumulated moisture from the fabric when removing.

#5 Make sure that the edges of the fabric are completely touching the ground and there are no open areas where heat can escape in order to trap as much heat as possible.

#6 Leave fabric when air temperature in the tunnels is at or below freezing or on cloudy days.

#7 If the weather forecast is favorable and the fabric needs to be pulled back, wait for the air temperature in the tunnel to reach 40-45ºF. Often it is warm enough by 10:00 am, even when very cold outside.

#8 If work needs to be done in the houses and it is cloudy and cold in the tunnels, uncover small areas at a time and recover when work is done.

#9 During the coldest part of the winter, Nov 15-March 1, elevated air temperatures in the tunnel over 70F will be allowed for up to several hours. Only open doors and vents in the winter to allow excess moisture and heat to escape when the sun is very bright and temperature will be >80F for several hours. Excess moisture and heat can be ventilated in a short time later in the day if necessary.

#10 Try to keep the frost fabric as clean as possible so that the light transmission remains high. Move fabric out of the way when watering to help keep it dry. Avoid holes or tears.