Environmental Control for Greenhouse-Grown Sweetpotato Slips

Greenhouses are used to protect plants from extreme temperatures, rain, sleet, snow, wind, hail, insects, and diseases. Their purpose is to provide a controlled environment to optimize plant growth and development, not just to avoid extremes in the weather. They can provide an ideal growing environment through manipulation of air temperature and quality, humidity, light, water, and fertilizer.

This publication outlines recommendations for selecting and constructing a greenhouse for virus-tested sweetpotato slip production in Mississippi. Virus-tested sweetpotato slips are the source of clean plant material for production of certified foundation seed roots for the state of Mississippi. Certified seed roots produced from virus-tested, clean plant material provide stakeholders with high-quality, "true-to-type" varieties to maximize commercial yield potential.

Figure 1. Greenhouse-grown sweetpotato plants.

Site Selection

Select a site that has access to both electricity and fresh, potable water. The water source should be from a public water system or private well, not surface water. It is best to test the pH and adjust it to 5.6 to 6.0.

Choose an area with no shading from trees or tall buildings. Be sure there are no shadows during the early morning or late afternoon hours. Sweetpotato plants require full sunlight for rapid growth and development. However, once slip production is complete and full sunlight is not necessary, the greenhouse can be shaded with shade cloth or shade compound.

Choose a site with room for possible future expansion. You may want to start with only one greenhouse, but locate it so there is ample room to add more greenhouses if needed later. Also consider topography; choose a well-drained site where water does not collect. Drainage should be one of your first considerations. If the soil is mostly sand, water will percolate directly through the soil under the greenhouse. However, many soils in Mississippi have a large clay component. In poorly drained soils, water drainage must be designed into the system.

Orientation

Position greenhouses to face a north–south direction rather than east–west. This siting becomes even more important as bays are added in a gutter-connected formation. The shadow caused by the gutter will leave an immobile shadow in an east–west range, whereas in a north–south range, the gutter shadow will move across the crop during the day as the sun moves from east to west.

Locate exhaust fans on the downwind end of the greenhouse so they are not exhausting into the wind. Locate the intake vents on the prevailing wind end (the direction wind typically blows from).

Type of Greenhouse

Greenhouses may be free-standing, single greenhouses or gutter-connected bays. If you plan to build more than one greenhouse, the gutter-connected formation is more economical. Each side-by-side pair of houses will share a common gutter, reducing the number of sidewalls by two, which decreases construction costs. In addition, less surface area means less heat loss, which will save energy.

The length of greenhouses used for sweetpotato slip production varies. A greenhouse longer than 150 feet will have too much of a temperature gradient from the air intake end to the exhaust end and is not recommended. If the greenhouse is longer than 150 feet, consider ventilating across the width of the greenhouse.

Quonset-style greenhouse structures (Figure 2) with a double poly plastic film covering are common for sweetpotato slip production, but a peak-style structure is also a good choice.

Foundation

Pressure-treated wood foundations are common for greenhouses (Figure 3). The wood used should be the exact perimeter dimensions of the greenhouse. The site should be level or, if desired, have at least a 1–2 percent slope from one end of the site to the other. For better drainage, dig 6-inch trenches under where the rows of benches/tables will go. Next, cover the floor with heavy black plastic. This will prevent contact between soil-borne organisms and plants in the greenhouse. If ditches were installed, fill them with pea gravel. Spread 2–3 inches of pea gravel over the whole foundation until level. Cover the pea gravel with woven plastic (Figure 4), which will allow water to drain from the greenhouse.

Another foundation option is a concrete slab. Concrete formed with a slight slope to a floor drain is preferred because it is easier to clean and sanitize.

Insect Screening

For the production of foundation sweetpotato slips, it is important that the greenhouse remains insect-free. Aphids and whiteflies especially are known to vector sweetpotato viruses from infected to healthy plants. Placing insect screens over any openings is a crucial step in reducing insect infiltration. A no-thrips insect screen (150 × 150 microns) is recommended.

Installing insect screens will decrease air flow to your vents up to 50 percent. The surface area of the insect screening must be up to 50 percent greater than the air intake opening to compensate for the decreased air flow (Figures 5 and 6).

Heating

There are several choices of heating systems to heat greenhouses, including natural gas (methane), LP gas (propane), No. 2 diesel oil, wood, electricity, or even a heat pump. Selecting the appropriate heating equipment may depend on the availability of fuel in a given area. Natural gas (Figure 7) and propane are clean-burning fuels that require minimal maintenance. A continuous supply of natural gas is a good option, but it is not always available in all areas. Propane requires storage tanks that will need to be monitored to minimize the risk of depleting fuel in cold weather.

Figure 2. A Quonset-style greenhouse covered with double poly plastic and with a pressure-treated wood foundation.

Figure 3. Wooden foundation with pea gravel.

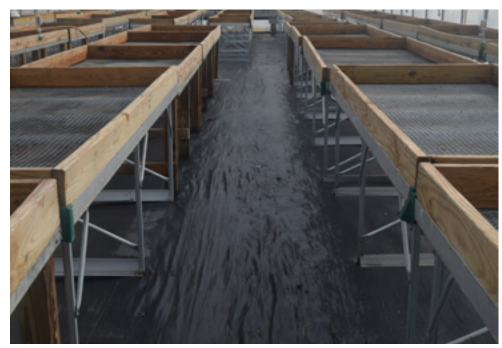

Figure 4. Greenhouse foundation consisting of woven black plastic over pea gravel.

Figure 5. Insect-screened area on the front of a greenhouse; it is also used as a double entry.

Figure 6. Insect-screened area on the back of a greenhouse.

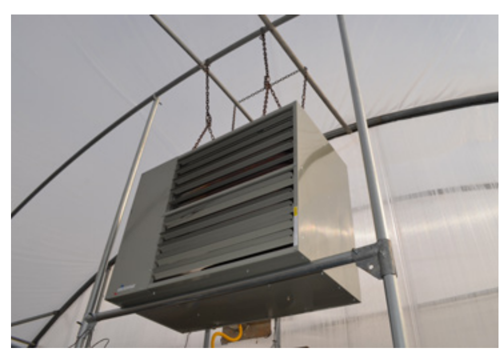

Figure 7. Natural gas heater mounted from the ceiling with a stand for additional support.

Unless using a heat pump or an electric heater, vent all burners to the outside. Never allow exhaust gases to remain inside the greenhouse, as sweetpotato slips are very sensitive to certain pollutants found in fossil fuel exhaust. Especially with kerosene and propane space heaters, it is possible to poison plants with toxic pollutants or expose them to ethylene gas. Also, space heaters may consume and deplete oxygen levels, which can result in incomplete combustion and produce harmful by-products, such as carbon monoxide. In addition, the lack of oxygen may cause the flame to go out and the burner to shut off. In either case, using unvented heaters is too risky.

In a tight plastic greenhouse, it may be necessary to bring fresh outside air to the burner via a duct to ensure complete combustion. See Providing an Air Intake for information on the correct size.

Other features to look for when choosing a heating system include thermostats, aluminized or stainless steel heat exchangers, fans to distribute heat, and mounting equipment.

How to Size the Heating Units

The following four steps can help you calculate the size of the heating system needed to keep sweetpotato slips at the required temperature (over 62°F).

Temperature Difference

Determine the greatest difference between inside and outside temperature for your region. Size your heating systems for the most extreme conditions expected. For example, do not base the BTU rating of the heaters on 40°F winters because the temperature often drops below 40°F in Mississippi. The 99 and 97.5 percent design temperatures for various cities in Mississippi are shown in Table 1. In Tupelo, 99 percent of recorded hourly temperatures in December, January, and February were above 14°F, and 97.5 percent of recorded temperatures during these months were above 19°F. Therefore, to be safe, size the heating system to provide adequate heat even when the temperature outside falls as low as 14°F. In northern Mississippi, from Greenville to Tupelo and farther north, the heating system should be designed for 14°F.

The inside temperature for greenhouse sweetpotato slips should not go below 62°F. Therefore, the maximum expected temperature difference is 48°F (62 - 14 = 48°F) for Tupelo, Mississippi. (See Table 1.)

Table 1. Design temperatures for selected cities in Mississippi.

City	99% Design Temperature	97.5% Design Temperature
Biloxi	28	31
Clarksdale	14	19
Columbus	15	20
Greenville	15	20
Greenwood	15	20
Hattiesburg	24	27
Jackson	21	25
Laurel	24	27
McComb	21	26
Meridian	19	23
Natchez	23	27
Tupelo	14	19
Vicksburg	22	26

Surface Area

Know the entire surface area of the greenhouse, including the total area of the side walls, end walls, and roof, expressed in square feet.

U-Value

Use the appropriate U-value (heat flow coefficient). For a double layer of plastic, use U = 0.8. If a thermal screen is used, the U-value would be 0.5. The lower the U-value, the better the insulation effect.

Calculate

Next, use the following equation:

$$\text{heat required} = U \times A \times (T_{inside} - T_{outside})$$

U = heat flow coefficient
A = surface area of greenhouse
$(T_{inside} - T_{outside})$ = maximum difference between inside and outside temperatures

Example: Assume a single 24-by-96-foot greenhouse in Tupelo, with a double layer of plastic, needs to be sized for a heating system.

If the gutter height is 8 feet, the surface area of each end wall is 192 square feet (24 feet × 8 feet). The side walls are each 768 square feet (96 feet × 8 feet). The surface area of the roof is the same as the width of plastic over the roof multiplied by its length. So, if the roof is 30 feet, the roof surface area is 2,880 square feet (30 feet × 96 feet). The total greenhouse surface area is (2 × 192) + (2 × 768) + 2,880 = 4,800 square feet.

Using the formula above:

$$\text{heat required} = U \times A \times (T_{inside} - T_{outside})$$

$$= 0.8 \times 4{,}800 \times (62 - 14)$$
$$= 0.8 \times 4{,}800 \times 48$$
$$= 184{,}320 \text{ BTUs}$$

A heating system able to supply a total of 185,000 BTUs would be appropriate for a greenhouse of this size located in Tupelo, Mississippi. It is better to use two small heaters (for example, two 93,000 BTU heaters) than one large heater in a single, free-standing greenhouse. If one heater fails, there will be a backup to prevent the crop from freezing.

Providing an Air Intake

Now that you know the size of the heating system, you can size the air intake for the heating unit (Figure 8).

Use this formula:

50 square inches of intake for each 100,000 BTUs of the heating system

If 185,000 BTUs are needed, as in the example above, use $1.85 \times 50 = 92.5$ square inches of air intake for the burners.

Thermostat

Each environmental control device needs a thermostat to control when it is activated to turn on and deactivated to turn off. This includes any or all of the following: heater, exhaust fan, fan jet louver, poly vent, evaporative cool pads, and/or mist system. The location of these thermostats is very important. Do not put thermostats on an outside wall; put them somewhere in the interior of the greenhouse where the temperature monitored will represent most of the plant space.

Locate thermostats near the center of the house and at plant level to get good temperature control. Also, enclose the thermostat in an aspirated box or shade it so that the thermostat can monitor air temperature correctly. If the sun is allowed to shine directly on the thermostat, it will read a higher temperature than the air surrounding it.

Do not put thermostats where hot air from the heater or cool air from the fans will blow directly on them.

Never trust a thermostat to be 100 percent accurate. It is wise to install a high/low thermometer in the greenhouse near the thermostat. It will record the highest and lowest temperatures that occurred since the last reset of these values. It is important to maintain the actual temperature desired. This temperature can be verified by the thermometer, regardless of what the thermostat setting displays.

Ventilation

Ventilation is important not only during the warm-season months, but also during the cool season on sunny days. Fresh air is primarily needed to lower the humidity and air temperature, but it also replenishes carbon dioxide (CO_2) that plants consume during the daylight hours in the process of photosynthesis.

Design the ventilation system (Figure 9) so that it moves 8–10 cubic feet per minute (CFM) of air per square foot of greenhouse space. For a 24-by-96-foot greenhouse, two 36-inch or 48-inch fans are usually required. Even with proper ventilation in the warm season, the inside temperature will always be higher than the outside temperature.

Figure 8. Heater intake (bottom) and exhaust (top) ducts leading from and to the outside.

Figure 9. A top ventilation fan and top intake louver provide ventilation for humidity and early temperature control.

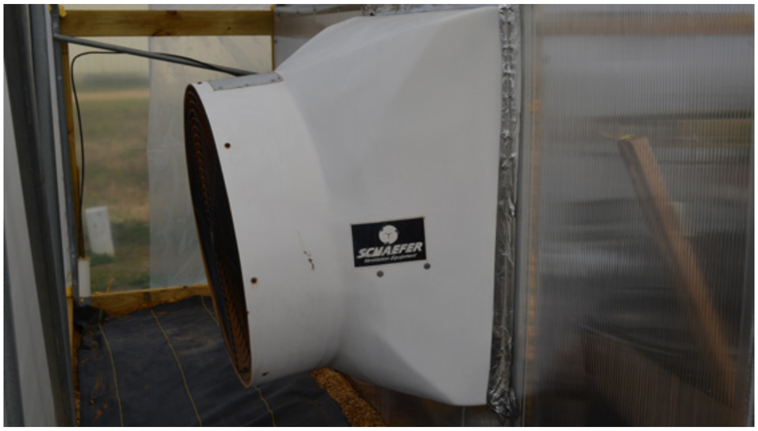

Figure 10. A 36-inch exhaust fan pulls air through a greenhouse from intake vents for temperature control.

Figure 11. Intake ventilation louvers open to allow air movement through the greenhouse for temperature control.

How to Size the Exhaust Fans

Use this formula:

exhaust fan CFM = 8 × (length of greenhouse) × (width of greenhouse)

Example: In a 24-by-96-foot greenhouse, the floor is 2,304 square feet. To calculate the CFM of the fans, multiply 8 × 2,304 = 18,432 CFM. This will give one air exchange per minute for the volume of air in the greenhouse up to a height of 8 feet.

If you use variable-speed fans or two-speed fans, you can control temperature more effectively. Be sure to keep any doors and windows at the fan end of the greenhouse closed while the fan is operating; otherwise, air currents will short circuit the greenhouse interior. Fit plastic coverings and poly vents tightly to prevent air leaks.

Be sure not to exhaust hot air from one greenhouse into the intake vent of another. This only compounds the cooling problem. Have shutters on fans that close automatically when they stop blowing.

How to Size the Intake Vent

Use this formula:

vent (sq ft) = 8 × (length of greenhouse) × (width of greenhouse) ÷ 700

Example: In a 24-by-96-foot greenhouse, the floor is 2,304 square feet. To calculate the volume of air that must be moved, multiply this number by a height of 8 feet, which is 2,304 × 8 = 18,432 cubic feet. Have adequate ventilation to achieve approximately one air exchange per minute, or, in this case, 18,432 cubic feet per minute (CFM). Wind velocity needed at the intake vent is 700 feet per minute.

Divide the cubic feet per minute by 700 feet per minute to get the square feet of the intake vent. This is calculated by dividing 18,432 by 700, which equals 26.3. So a minimum of 27 square feet of intake vent is required. It is better to have the intake vent span the whole width or most of the end wall rather than placing all 27 square feet into one square or small, rectangular-shaped vent. For greenhouses with an insect barrier over the intake vent (Figure 11), increase the vent size to compensate for reduced air flow. Contact the manufacturer for information.

Evaporative Cooling

In addition to cooling by using exhaust fans, often you will need to take additional measures. One of the most common measures is to add evaporative cooling, also referred to as wet pads or cooling pads. The principle is simple. As the exhaust fans blow air out of one end of the greenhouse, they draw in warm air across the cooling pads. As the warm air moves through the cooling pads, water evaporates and absorbs heat, resulting in cool air moving through the greenhouse.

Moisture is supplied at the end opposite the fans with a system that drips water through an absorbent material, such as cellulose (typically 4 or 6 inches thick) or aspen pads. All incoming air passes through this wet fiber. Any water that drips through the fiber is collected in a gutter at the bottom and drains into a small holding tank. Water is recirculated from the holding tank back to the top of the cooling pads. Because aspen pads last a maximum of only 1–2 years in the southern climate, they are not recommended.

Be sure to replace water that is absorbed by the air passing through the cool pads. This is usually done with a toilet tank-type float-valve controller.

Evaporative cooling is more effective when the air outside the greenhouse has a low relative humidity. As the relative humidity of the outside air increases, this technique becomes less effective. For example, if the outside air is 95°F and the relative humidity is 50 percent, there would be about 13°F of effective cooling. But if the relative humidity is 70 percent, there would be only an 8°F drop. With 90 percent relative humidity, you can expect only a 2°F drop.

So long as the relative humidity is less than 100 percent, this method will have some cooling effect on the air.

Choosing the correct pad size is important to achieve adequate cooling. The length of the pads is limited by the greenhouse width, so it is the height that must be calculated.

How to Size the Cool Pads

pad height (feet) = (air flow rate) ÷ (pad length) ÷ (design velocity)

The air flow rate is the same as the cubic footage of the greenhouse. In a 24-by-96-foot greenhouse, use 24 × 96 × 8, because the usable height for cooling is 8 feet. This equals 18,432 cubic feet. Because you need one air exchange per minute, 18,432 CFM is the air flow rate. The pad length should be about 2 feet less than the greenhouse width, or 22 feet in this example.

The design velocity is the speed with which air can pass through the cooling pad, in feet per minute. For 4-inch cellulose, as in this example, use 250; for 6-inch cellulose, use 380; and for aspen pads, use 165.

So the equation above becomes:

(18,432) ÷ (22) ÷ (250) = 3.35 feet

This means that a pad 22 feet long needs to be 3.35 feet high, or a minimum of 3 feet 4 inches. For ease of construction, extend the pad height to 4 feet.

Horizontal Air Flow

Horizontal air flow refers to movement of air within the greenhouse, as opposed to drawing fresh air in from outside. This inside air movement is important to the health and productivity of greenhouse crops. It is necessary to have air movement within the greenhouse at all times, whether the exhaust fans are on or not. When exhaust fans are not in use, make some other provision to create air movement within the greenhouse.

Constant air movement is important for the following reasons:

- It maintains a more uniform environment throughout the greenhouse, avoiding "pockets" of high or low temperature or humidity.
- Air movement helps to keep leaf surfaces dry so diseases are less likely to develop.
- The air will also help to dry the inside surface of the plastic covering. Any condensation on the plastic film will reflect some light rather than transmitting it to plants; in effect, it causes shading.
- It brings carbon dioxide to the leaf surfaces. In the absence of air movement, carbon dioxide, essential for photosynthesis, can actually be depleted adjacent to leaves even though it is more available in other parts of the greenhouse. Air movement keeps carbon dioxide mixed throughout the greenhouse.

One way to provide continuous air flow is to set the fan on the heater to remain on constantly. Another option is to wire a separate thermostat to the heater fan so that it can be set to turn on when exhaust fans are off and heat is not needed. The heater thermostat will still control when the burner comes on, but the fan will stay on more regularly. When exhaust fans are on, they will provide all the air-mixing needed.

Another technique is to install low-volume horizontal air flow (HAF fans) (Figure 12) above the plants to push air around the greenhouse. These are left on all the time or wired so they turn off when the exhaust fans come on. Horizontal air flow keeps the air moving among the plants at all times.

Figure 12. Horizontal fans provide air movement within the greenhouse.

Plastic Film

The plastic film used to cover greenhouses comes in various formulations that affect its longevity.

Generally, it is sold as 2-year, 3-year, 4-year, or unspecified-length options. Film rated 2-year or higher has UV (ultraviolet) inhibitor in it to prevent rapid breakdown from the sun. A film with an unspecified life span will probably last less than a year with Mississippi's high UV index, so it is not worth the cost.

The longer the life of a film, the more expensive it is. Although initially more expensive, longer life films require less frequent replacement, which reduces labor costs.

The best compromise between longevity and price is a 3-year film. Make sure it is "UV-resistant" and the correct size to cover the greenhouse with a little left over to fasten around the edges.

Double Plastic Cover

One technique used to reduce heat loss is to apply two layers of plastic film to the surface of the greenhouse rather than one layer of film or glass. This double layer is often referred to as double poly. A single layer has a U-value (heat flow) of about 1.2, while two layers bring the U-value down to 0.8 (the lower the U-value, the better the insulation). Also, the air space between the two layers is inflated and serves as an excellent insulation to decrease heat loss. Using this simple method gives an energy savings of about 30 percent.

However, there are two important points:

- Do not allow the two layers of plastic to touch each other except where fastened. Any point where the two layers come in contact is reduced to an insulating value of one layer. To avoid this, use a small blower (Figure 13) to inflate the space between the two layers of plastic. A ⅓- or ¼-horsepower squirrel-cage fan (100–200 watts) is usually adequate for this purpose. This blower should run constantly to maintain inflation.
- It is important to use outside air for this purpose. Although inside air is warmer and will use less energy to heat, it holds more moisture than the cooler outside air. Often, greenhouses that use inside air will have water collect between the layers, making small pools of water. If this happens, puncture the lower layer to let the water drain; then patch the hole. Otherwise, the weight of the water can tear the plastic.

Water collects because the warm, humid air blown between the layers from inside the greenhouse comes in contact with the outside layer of plastic. This outside layer is cooler. If the temperature of the outside layer is below the dew point, as it usually is in the winter, it causes water to condense from the air onto the cool surface. This water collects between the layers into pools that grow with time.

Figure 13. A squirrel-cage blower (fan) is used to inflate between the two layers of plastic covering the greenhouse.

Supplemental Lighting

Light-emitting diode (LED) vegetative supplemental lighting (Figure 14) is used to increase vine growth of sweetpotato slips. It is important to select LED lights that are specifically for vegetative growth (heavier blue-light concentration) and not full-spectrum LED lights. Full-spectrum LED lights will increase flowering, which is not desired for sweetpotato slip production. Do not use lights until after roots are established, about a week after planting. Frequency and duration of use will depend on the time of year slips are being produced and the amount of cloud coverage/sun exposure. Supplemental lighting is used to provide light during extended periods of cloud coverage and/or to extend day length during winter months.

Figure 14. An LED vegetative supplemental growth light.

Publication 3368 (POD-12-25)

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Produced by Agricultural Communications.

Extension Service of Mississippi State University, cooperating with U.S. Department of Agriculture. Published in furtherance of Acts of Congress, May 8 and June 30, 1914. ANGUS L. CATCHOT JR., Director