Greenhouse Temperature Management

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Introduction

One of the benefits of growing crops in a greenhouse is the ability to control all aspects of the production environment. One of the major factors influencing crop growth is the temperature. Different crop species have different optimum growing temperatures and these optimum temperatures can be different for the root and the shoot environment, and for the different growth stages during the life of the crop. Since we are usually interested in rapid crop growth and development, we need to provide these optimum temperatures throughout the entire cropping cycle. If a greenhouse were like a residential or commercial building, controlling the temperature would be much easier since these buildings are insulated so that the impact of outside conditions is significantly reduced. However, greenhouses are designed to allow as much light as possible to enter the growing area. As a result, the insulating properties of the structure are significantly diminished and the growing environment experiences a significant influence from the constantly fluctuating weather conditions. Solar radiation (light and heat) exerts by far the largest impact on the growing environment, resulting in the challenge maintaining the optimum growing temperatures. Fortunately, several techniques can be used to reduce the impact of solar radiation on the temperature inside a greenhouse. These techniques are further discussed in this article.

Ventilation

Greenhouses can be mechanically or naturally ventilated. Mechanical ventilation requires (louvered) inlet openings, exhaust fans, and electricity to operate the fans. When designed properly, mechanical ventilation is able to provide adequate cooling under a wide variety of weather conditions throughout many locations in the United States.

Natural ventilation (Figure 1) works based on two physical phenomena: thermal buoyancy (warm air is less dense and rises) and the so-called “wind effect” (wind blowing outside the greenhouse creates small pressure differences between the windward and leeward side of the greenhouse causing air to move towards the leeward side). All that is needed are (strategically located) inlet and outlet openings, vent window motors, and electricity to operate the motors. In some cases, the vent window positions are changed manually, eliminating the need for motors and electricity, but increasing the amount of labor since frequent adjustments are necessary. Compared to mechanical ventilation systems, electrically operated natural ventilation systems use a lot less electricity and produce (some) noise only when the vent window position is changed. When using a natural ventilation system, additional cooling can be provided by a fog system. Unfortunately, natural ventilation does not work very well on warm days when the outside wind velocity is low (less than 200 feet per minute). Keep in mind that whether using either system with no other

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cooling capabilities, the indoor temperature cannot be lowered below the outdoor temperature.

Due to the long and narrow design of most freestanding greenhouses, mechanical ventilation systems usually move the air along the length of the greenhouse (the exhaust fans and inlet openings are installed in opposite end walls), while natural ventilation systems provide crosswise ventilation (using side wall and roof vents).

In gutter-connected greenhouses, mechanical ventilation systems inlets and outlets can be installed in the side- or end walls, while natural ventilation systems usually consist of only roof vents. Extreme natural ventilation systems include the open-roof greenhouse design, where the very large maximum ventilation opening allows for the indoor temperature to almost never exceed the outdoor temperature. This is often not attainable with mechanically ventilated greenhouses due to the very large amounts of air that such systems would have to move through the greenhouse to accomplish the same results.

When insect screens are installed in ventilation openings, the additional resistance to airflow created by the screen material has to be taken into account to ensure proper ventilation rates. Often, the screen area is larger compared to the inlet area to allow sufficient amounts of air to enter the greenhouse.

Whichever ventilation system is used, uniform air distribution inside the greenhouse is important because uniform crop production is only possible when every plant experiences the same environmental conditions. Therefore, horizontal airflow fans are frequently installed to ensure proper air mixing. The recommended fan capacity is approximately 3 cfm per ft^2 of growing area.

Humidity Control

Healthy plants can transpire a lot of water, resulting in an increase in the humidity of the greenhouse air. A high relative humidity (above 80-85%) should be avoided because it can increase the incidence of disease and reduce plant transpiration. Sufficient venting, or successively heating and venting can prevent condensation on crop surfaces and the greenhouse structure. The use of cooling systems (e.g., pad-and-fan or fog) during the warmer summer months increases the greenhouse air humidity. During periods with warm and humid outdoor conditions, humidity control inside the greenhouse can be a challenge. Greenhouses located in dry, dessert environments benefit greatly from evaporative cooling systems because large amounts of water can be evaporated into the incoming air, resulting in significant temperature drops.

Since the relative humidity alone does not tell us anything about the absolute water holding capacity of air (we also need to know the temperature to determine the amount of water the air can hold), a different measurement is sometime used to describe the absolute moisture status of the air: the vapor pressure deficit (VPD). The vapor pressure deficit is a measure of the difference between the amount of moisture the air contains at a given moment and the amount of moisture it can hold at that temperature when the air would be saturated (i.e., when condensation would start; also known as the dew point temperature). A vapor

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pressure deficit measurement can tell us how easy it is for plants to transpire: higher values stimulate transpiration (but too high can cause wilting), and lower values inhibit transpiration and can lead to condensation on leaf and greenhouse surfaces. Typical VPD measurements in greenhouses range between 0 and 1 psi (0-7 kPa).

Cooling

When the regular ventilation system is unable to provide sufficient cooling for greenhouse temperature control, additional cooling is needed. Two cooling systems, the pad-and-fan and the fog system, are commonly used in greenhouses and both make use of the cooling effect resulting from the evaporation of water (Figures 2 and 3). The process of evaporation requires heat that is removed from the air surrounding the evaporating water. Pad-and-fan systems can only work in combination with mechanical ventilation: an evaporative cooling pad is installed in the ventilation opening, cooling the incoming air. As the air moves through the greenhouse towards the exhaust fans, it picks up heat from the greenhouse environment. Therefore, pad-an-fan systems experience a temperature gradient between the inlet (pad) and the outlet (fan) side of the greenhouse. This temperature gradient should be minimal to provide all plants with similar conditions. However, a gradient of 7-10°F is not uncommon.

Fog nozzles can be installed throughout the greenhouse, resulting in a more uniform cooling pattern compared to the pad-and-fan system. The recommended spacing is approximately one nozzle for every 50-100 ft^2 of growing area. The water pressure used in greenhouse fog systems is very high (500 psi and higher) in order to produce very fine droplets that evaporate before the droplets can reach plant surfaces. The water usage per nozzle is small: approximately 1-1.2 gph. In addition, the water needs to be free of impurities to prevent clogging of the small nozzle openings. As a result, water treatment and a high-pressure pump are needed to operate a fog system. The usually small diameter supply lines should be able to withstand the high water pressure. Therefore, fog systems can be more expensive to install compared to pad-and-fan systems.

The required evaporative pad area depends on the pad thickness. For the typical, vertically mounted four-inch thick pads, the required area (in ft^2) can be calculated by dividing the total greenhouse ventilation fan capacity (in cfm) by the number 250 (the recommended air velocity through the pad). For six-inch thick pads, the fan capacity should be divided by the number 350. The recommended minimum pump capacity is 0.5 and 0.8 gpm per linear foot of pad for the four and six-inch thick pads, respectively. The recommended minimum sump tank capacity is 0.8 and 1 gallon per ft^2 of pad area for the four and six-inch pads, respectively. For evaporative cooling pads, the estimated maximum water usage is 20-30 gpm per 100 ft^2 of pad area. Approximately 10% (or 0.005 gpm per 1000 cfm of air flow when using water with a salt concentration of less than 700 ppm, or three times as much when the salt concentration is as high as 1,500 ppm) of the returning water should be bled off to prevent salt buildup on the pads. Salt buildup reduces the efficiency of the pads. It is recommended that the pads be dried out overnight to prevent the growth of algae.

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Shading

Investing in movable shade curtains (Figure 4) is a very smart idea, particularly with the high energy prices we are experiencing today. Shade curtains help reduce the energy load on your greenhouse crop during warm and sunny conditions and they help reduce heat radiation losses at night. Energy savings of up to 30% have been reported, ensuring a quick payback period based on today's fuel prices. Movable curtains can be operated automatically with a motorized roll-up system that is controlled by a light sensor. Even low-cost greenhouses can benefit from the installation of a shade system. The curtain materials are available in many different configurations from low to high shading percentages depending on the crop requirements and the local solar radiation conditions. Movable shade curtains can be installed inside or outside (on top or above the glazing) the greenhouse. Make sure that you specify the use when you order a curtain material from a manufacturer. When shade systems are located in close proximity to heat sources (e.g., unit heaters or CO_2 burners), it is a good idea to install a curtain material with a low flammability. These low flammable curtain materials can stop fires from rapidly spreading throughout an entire greenhouse when all the curtains are closed.

Figure 1. Natural ventilation.

Figure 2. Evaporative cooling pads.

Figure 3. Greenhouse misting system.

Figure 4. Internal shade system.

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