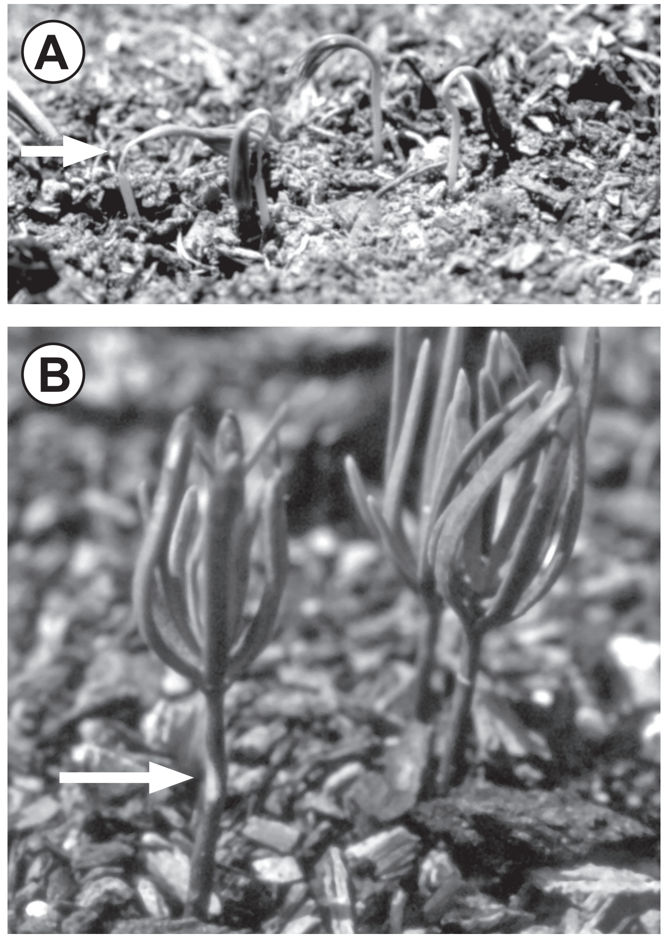
Using Water to Cool Nursery Crops

by Thomas D. Landis

Heat injury to nursery seedlings has been a problem since the early 1900s, and considerable research was done over the following 25 years to develop cultural practices to prevent it. Although growth losses due to excessive heat undoubtedly occur, the most obvious damage has been stem girdling of newly emerged seedlings by direct sunlight (Hartley 1918). Young, newly emerged, succulent seedlings are killed by a constriction at the ground line (Figure 1A), whereas older nursery stock often develops a white spot on the sunny side of the stem (Figure 1B). Vigorous plants may be able to outgrow this injury but others form a stem canker that causes structural weakness. The stem of damaged seedling may eventually bend or even break at the injury site (Barnard 1990).

Although this damage is more common in seedbeds, both bareroot and container stock have been affected. Cooling with irrigation or "water shade" has been proven effective in numerous studies. For example, midday sprinkler irrigation reduced surface soil temperatures almost 30°F (16.6°C) and the cooling effect lasted for more than 4 hours (Stoeckeler and Slabaugh 1965; Figure 1C).



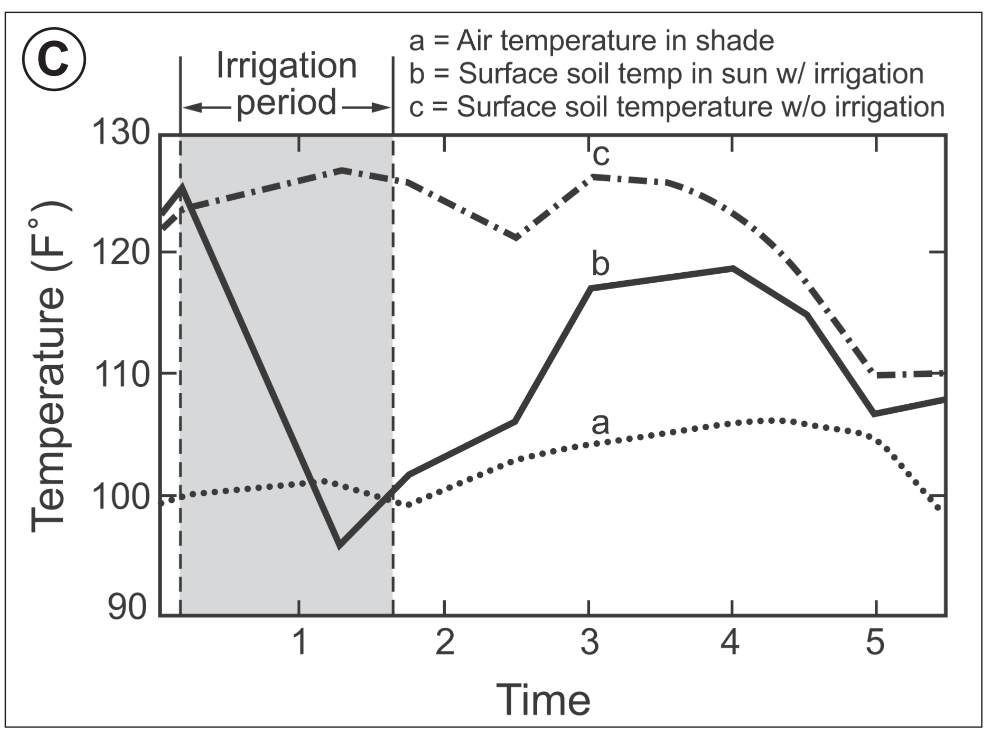


Figure 1 - The most serious type of heat injury to nursery crops is damage to stem tissues in succulent young seedlings, causing stem girdling (A) or cankers (B). The cooling effect of irrigation has been proven in a research trial at a North Dakota bareroot nursery where midday sprinkler irrigation significantly reduced surface soil temperatures for more than 4 hours (C) (C - modified from Stoeckeler and Slabaugh 1965).

1. The basic physics

Before we go any further, let us review some basic concepts of heat transfer. Heat is usually known as sensible heat, which is the familiar type that we can measure with a thermometer. Latent heat, on the other hand, is related to phase changes from a gas to a liquid or from a liquid to a solid. When water freezes into ice, heat is given off in an exothermic reaction; however, when liquid water evaporates, heat is absorbed — an endothermic reaction. Water has the highest latent heat of vaporization of all common liquids (540 calories per gram), which means that when growers apply sprinkler irrigation on hot sunny day, the subsequent evaporation removes heat from their crops and their immediate environment. For each gallon of water that is evaporated, around 9400 Btu of heat are absorbed (Bartok 2003).

The potential for cooling with irrigation also depends on the atmospheric demand for water vapor - the vapor pressure deficit (VPD). The VPD is important in nursery work because it reflects the evapotranspirational demand of the surrounding atmosphere, which is important to know before you consider cooling with irrigation. VPD is primarily a function of temperature and relative humidity, although wind must also be considered (Landis and others 1992). For example, in an open bareroot field (Figure 2A), the VPD would be much greater than that in a closed greenhouse (Figure 2B). Even in the humid southeastern states, the potential exists for 10 to 20 °F (5.5 to 11.0 °C) of cooling below the ambient temperature during the warmest part of the day (Bartok 2003).

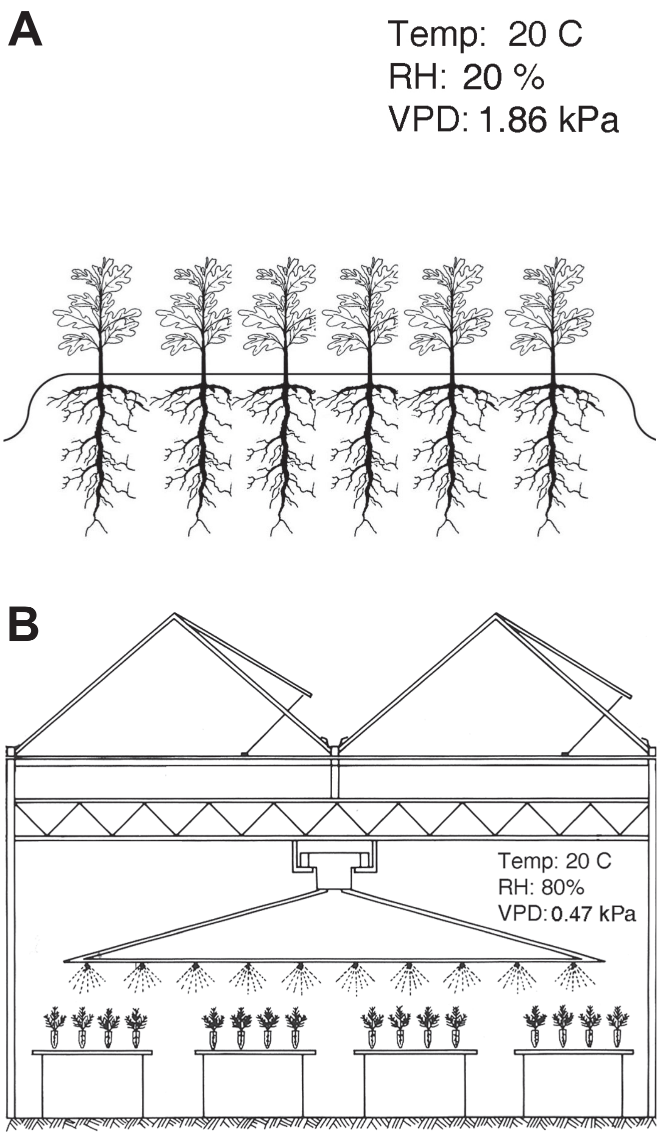


Figure 2 - The vapor pressure deficit (VPD) is a reflection of the evapotranspirational demand of the atmosphere surrounding the crop. VPD will always be higher in bareroot beds (A) and open compounds than in enclosed structures such as greenhouses (B).

Figure 3 - Irrigation water quality is critical to the success of cooling with irrigation. Water with high levels of dissolved salts can plug irrigation nozzles and leave unsightly spots on plant foliage.

2. Importance of water quality

Although any water source can be used to cool plants on a hot day, water with a low level of dissolved salts will cause less problems (Evans and van der Guzik 2011). When water evaporates, it leaves behind any dissolved minerals (that is, salts) on your sprinkler heads or crops (Figure 3). The standard index of irrigation water quality is measured as electrical conductivity (EC). EC is a measure of the salinity (total salt level) of an aqueous solution. EC meters measure electrical charges carried by the salts that are dissolved in a solution — the more concentrated the salts, the higher the reading. All irrigation water contains some salt ions, the result of rain water trickling through soil and rocks; for instance, water percolating through calcareous rocks or soils picks up calcium, magnesium and bicarbonate ions. Because salts are left behind when surface water evaporates, irrigation water from dry climates will have higher EC readings than water from a humid climate (Landis and Dumroese 2006). These mineral deposits are particularly troublesome when using sprinkler irrigation to cool crops because the water application rates are too low to wash away excess salt deposits (Evans and van der Guzik 2011).

Table 1 - Irrigation water quality test criteria for cooling with irrigation (modified from Evans and van der Guzik 2011; Hopkins and others 2007).

Quality Indices (Do not exceed)	
pH	7.5
Electrical conductivity (EC)	2 dS/m (2 mmhos/cm)
Lime deposition potential (lesser of sum of Ca + Mg, or $C0_3$ + HCO_3	4 meq/l
Specific Ions Measured in parts per million (ppm or mg/l), or milliequivalents per liter (meq/l)	**Conversion Factors** To convert from ppm to meq/l, divide by this number; to convert from meq/l to ppm, multiply by the same factor
Calcium (Ca)	20
Magnesium (Mg)	12.2
Sodium (Na)	23
Chloride (Cl)	35.5
Carbonate ($C0_3$)	30
Bicarbonate (HCO_3)	61

So, before you consider cooling with irrigation, the first step is to take water a sample and have it chemically analyzed. Irrigation water quality is typically reported in units of parts per million (ppm), milligrams per liter (mg/l), or milliequivalents per liter (meq/l); conversion factors are provided in Table 1.

Several water quality indices can be used to determine whether your irrigation water is suitable for cooling your crops. The quickest test is EC: if the amount of total salts in the water is too high (EC > 2 dS/m), the water should not be used for crop cooling (Table 1). Irrigation water pH can also provide clues. When the pH of irrigation water exceeds 7.5, the potential for calcium carbonate precipitation is high (Evans and van der Guzik 2011). One of the most widely-used water quality indexes is the lime deposition potential (Hopkins and others 2007). Lime deposition occurs when calcium or magnesium carbonates precipitate out of irrigation water, leaving white residues or deposits. Water with a high lime deposition potential rating can cause crusts (scale) that can plug irrigation nozzles and white residues on plant foliage (Figure 3). These residues are not damaging in themselves but may reduce the saleability of your plants. The lime deposition potential of irrigation water is calculated from water test results as the lesser of the sum of the calcium and magnesium ions, or the sum of carbonate and bicarbonate ions. The higher the number, the higher the risk of lime deposition and irrigation waters with LDP values greater than 4 should not be used for irrigation cooling (Table 1).

Certain dissolved salt ions, such as chloride, can directly "burn" plant foliage. Crops vary considerably in their tolerance to chloride, but irrigation waters with less than 70 ppm chloride is considered safe for most plants (Hopkins and others 2007).

Unfortunately, irrigation water cannot be treated in any economical way to remove potentially damaging salts because of their associated energy costs. For example, reverse osmosis is very effective but the process is energy intensive and only about 10 percent of the original volume of water is usable after treatment (Hopkins and others 2007).

3. Methods of applying irrigation for cooling crops

In traditional agriculture, sprinkler irrigation has been used to reduce crop temperatures in 3 different ways (Evans and van der Guzik 2011):

Water evaporation in the air. When growers apply a fine mist of water to their crops, heat is absorbed from the surrounding air (Figure 4). This is the least efficient method, however, because the cooled air must reduce plant temperatures by convective heat transfer.

Hydrocooling. Water is applied directly to leaves and the sensible heat is carried away by liquid runoff. This would be impractical in forest, conservation, and native plant nurseries because it requires large quantities of water and leads to saturation of the soil or growing medium.

Sprinkler irrigation. When just enough water is applied to throughly wet plant foliage, the temperature of the leaves drops when the surface water evaporates back into the atmosphere (Figure 4). This relatively large amount of latent heat loss by means of conduction is the most effective way to cool crops.

3.1 Bareroot nurseries and open growing compounds

Although the evapotranspirational demand is always higher in bareroot seedbeds and open compounds than in enclosed structures, the only practical option for applying water to crops is through traditional sprinkler nozzles. "Water cooling" consists of brief applications of sprinkler irrigation, especially during seedling emergence when surface soil temperatures can exceed 112 °F (45 °C) on a warm. sunny day (Thompson 1984). The temperature at which irrigation for cooling is started gradually increases as seedlings become larger (Table 2). Soil color is critical as dark soils absorb the most solar insolation and sandy soils absorb more heat than finer-textures clays. The critical soil temperatures for cooling vary with seedling age and species. Therefore, species adapted to cooler and moister climates, such as Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*), are less tolerant to heat damage than most pines (McDonald 1984). Some nurseries use air

Table 2 - Generalized calendar guidelines for determining when to irrigate to cool surface soils during seedling emergence (Duryea and Landis 1984).

Calendar Date	Not to Exceed Soil Temperatures
Prior to July 1	90 °F (32 °C)
July 1 to August 1	95 °F (35 °C)
After August 1	100 °F (38 °C)

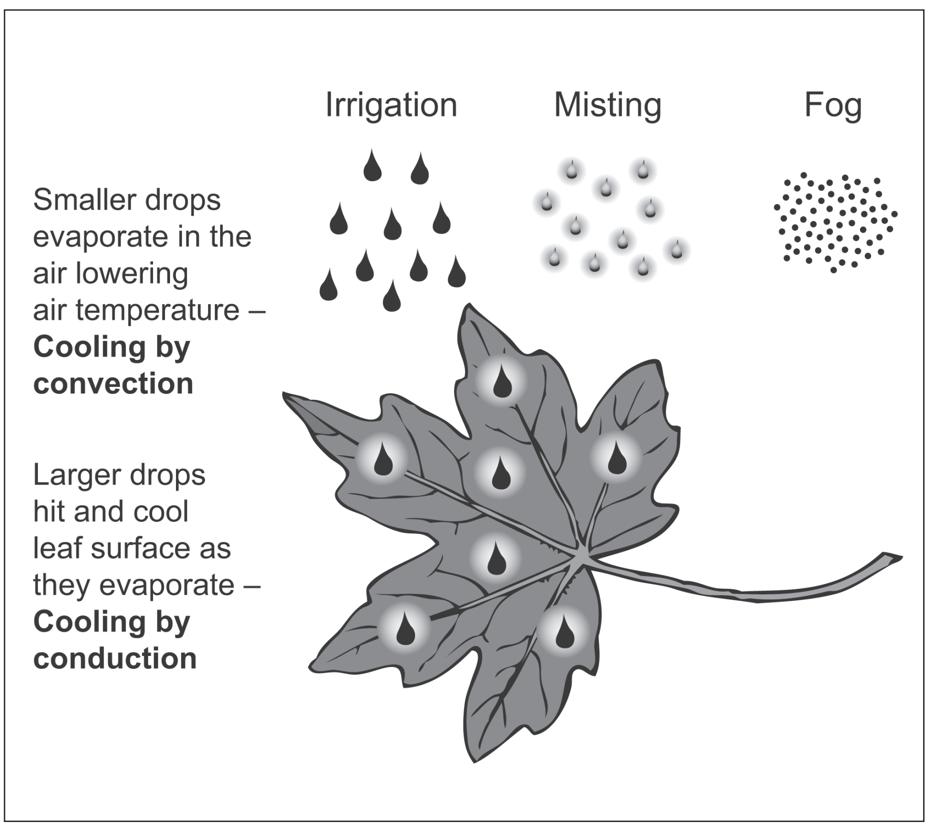


Figure 4 - Irrigation can be applied in 3 different droplet sizes to cool crops. The larger drops of from conventional irrigation nozzles (A) coat the plant foliage that is cooled when the latent heat of vaporization is removed by conduction. Mist nozzles create finer droplets (B) that cool the surrounding air through evaporation while some reach the leaf surfaces. Fog nozzles are the newest are create very fine droplets (C), which stay suspended until they evaporate. True fog does not create wet surfaces.

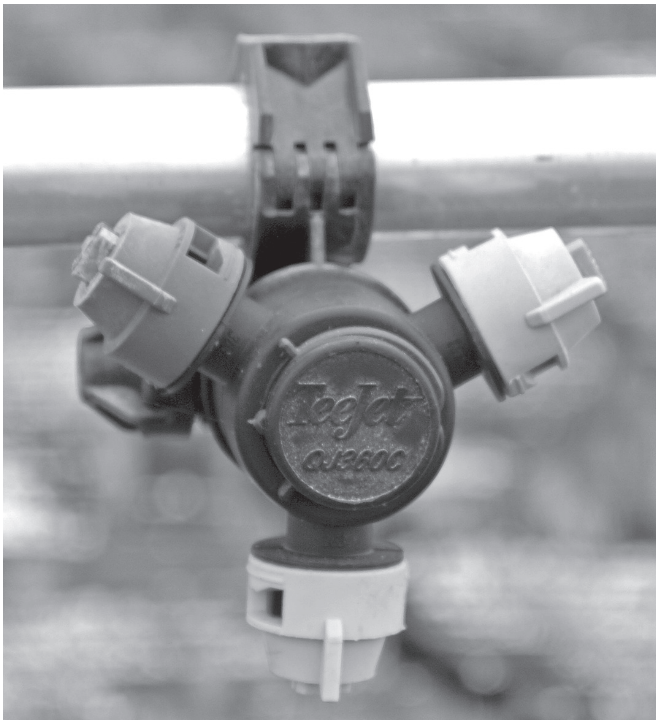


Figure 5 - Irrigation booms can be fitted with special nozzles that allow growers to change from standard irrigation to misting.

temperature to monitor when to water cool young seedlings but there is no substitute for actually measuring surface soil temperatures. Wind increases evaporation and reduces sprinkler efficiency so the US Forest Service JH Stone nursery in Medford irrigated for 30 min when wind speed was 6 mph and below but increased to 45 to 60 min when wind speed was higher (Morby 1982). In Southern nurseries, watering during the heat of the day can reduce surface soil temperatures by as much as 20 °F (11.1 °C) and the ambient air temperature may drop 10 to 15 °F (5.6 to 8.3 °C) or more, depending on humidity levels (May 1984). Sprinkler irrigation of pine seedlings in North Dakota reduced surface soil temperatures from 120 °F to 100 °F (48.8 to 37.8 °C) after 30 min of watering and this temperature reduction lasted for 4 hours or more (Figure 1C).

3.2 Container nurseries

Greenhouses and other enclosed structures offer a couple of more options for cooling crops with water: misting and fog. Misting requires a different type of nozzle than standard irrigation and fog requires a special high-pressure system. Boom irrigation offers a unique opportunity to manually switch from standard irrigation to misting using special rotating heads (Figure 5). In addition, the speed of irrigation booms can be increased to just wet plant foliage without saturating the growing medium.

Misting. Mist nozzles is the older technology that runs on standard irrigation water pressure of 20 to 100 psi (2 to 7 bars) but uses smaller nozzle orifices to generate smaller droplets (Figure 4). Misting is primarily used to cool the air and crops in propagation structures but also helps keep humidity high, which reduces transpirational water loss (Stanley 2011). Misting is ideally suited for keeping seeds "moist, but not wet" during germination and cooling surface temperatures during emergence. It can also be used, however, to cool the greenhouse environment on hot, sunny days. Be aware that many so-called fog systems from hardware stores or irrigation suppliers produce droplets larger than 50 microns so these are technically mist sytems (Bartok 2003).

Fog. Fog can be defined as water droplets around 10 micron (um) in diameter which, as a frame of reference is about 1/10th the diameter of a human hair (Figure 4). Fog systems use very pressure water (1,000 psi = 70 bars) to generate these fine droplets and specialized piping and nozzles are required. Because they use relatively little water (5 gph = 18.9 lph), water requirements are minimal. Greenhouses have been cooled as much as 27 °F (15 °C) by well-designed fogging systems (Stanley 2011). Although it can reduce plant water use, fogging is not intended to provide significant water for irrigation purposes and, because it doesn't wet plant foliage, the disease potential is less. Fog systems are typically used in greenhouses with natural ventilation systems and especially for propagating cuttings. When compared to wet wall and fan systems, properly designed fog systems produces more uniform cooling throughout the growing area (Both 2007). Fog systems are best managed through computerized environmental control systems that can continually monitor temperature and relative humidity and calculate vapor pressure deficits (Bartok 2003). Fogging requires water of the highest quality to keep the very small nozzle orifices from plugging with salt deposits.

4. Summary

Excessive heat can be a problem in both bareroot and container nurseries, although fully controlled greenhouses have more cooling options. Although stem injuries to succulent young seedlings is the most visible type of injury, prolonged hot spells induce severe moisture deficits that can be reflected in reduced growth rates. Growers should capitalize on the high latent heat of evaporation of water and cool their crops through irrigation, misting, or fog. Research has shown that the beneficial effects of irrigation can last many hours after the water has been turned off. The need for water cooling should be determined by routinely monitoring temperatures in the seedbed or at crop level in the greenhouse, especially during the critical periods of seed germination and seedling emergence.

5. References

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