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Reducing Heat Stress to Container-grown Plants

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Production of plants in containers offers many advantages over field production. Shorter production cycles, larger numbers of plants per acre, and the ability to continuously market and ship plants are among those advantages.

Container production also has disadvantages, including more intense cultural practices, a relatively short window of optimum marketability due to container size restrictions, and rapid daily temperature fluctuations within the container substrate (growing medium). Roots are generally less tolerant of temperature extremes than shoots. Plants have evolved to thrive and survive with roots growing in a large volume of soil that buffers roots from temperature extremes and rapid fluctuations. But in container nurseries the high surface area to volume ratio of production containers and the absorption of direct solar radiation by container surfaces expose plant roots to significant temperature fluctuations throughout a single day as well as seasonally. Root-zone temperatures for container-grown plants produced in the full sun will consistently exceed 104°F for 5 to 10 hours each day in some portion of the container. During summer months, temperatures near the west container wall will usually exceed 120°F, and temperatures higher than 130°F have been recorded. Even during winter months in the southern U.S., substrate temperatures near the south container wall in full sunlight can exceed critical thresholds for root damage.

This publication will provide information about plant response to high root-zone temperatures, identify critical temperatures, describe the factors that influence temperature fluctuations, and suggest cultural practices to reduce heat stress in container-grown plants.

Critical High Temperatures for Plant Roots

Plant responses to temperatures high enough to damage cell membranes in root tissue can be immediate. This kind of damage is known as **direct injury**. Direct injury occurs immediately at the cellular level in response to a short exposure to temperatures above a critical threshold, and the damage is visible soon thereafter. Roots with direct injury do not recover. Age of root tissue can impact the level of injury observed; large woody roots are more tolerant than smaller non-woody fleshy roots. Some recovery of root systems by regenerating from older woody roots has been observed, although it can be a slow process. This explains how container-grown plants might be able to recover from brief exposure to direct solar radiation that only damages the smaller roots near the container wall interface. Even short-term exposure of container sidewalls to sunlight when on display or in a staging area for landscape installation can contribute to "transplant shock" or delayed plant establishment in the landscape.

The critical temperature that results in direct injury to plant roots is not the same for all plant species. A list of some plants and the critical temperatures for direct injury to roots for an exposure of 20 to 35 minutes is shown in Table 1. The critical temperature that causes direct injury of roots in container-grown landscape plants after 30 minutes of exposure ranges from 113°F to 130°F. Direct injury of roots can also occur at slightly lower temperatures when exposed for 5 hours versus 30 minutes. However, we are not aware of a critical temperature causing direct injury below 108°F even with these longer exposures. That means we need to be concerned about temperatures in the root zone that approach 108°F and, as noted above, those temperatures occur frequently for many container-grown plants.

Plant physiological processes can be damaged by exposure to prolonged temperatures below those causing direct injury to root cell membranes. This damage is called **indirect injury**, caused by longer exposure to temperatures above optimal yet below lethal temperatures. Research has documented high root-zone temperature impacts on photosynthesis, carbon partitioning, respiration, water relations, hormone synthesis/response, nutrient uptake and utilization, and root diseases. Symptoms of indirect injury might include loss of plant vigor, modification of plant growth and form, premature leaf abscission and/or leaf discoloration caused by nutritional disorders, increased susceptibility to diseases, and other abnormalities in plant growth and developmental such as flowering and fruiting. Symptoms of indirect injury might not be visible or might go unnoticed when there are no control plants for comparison. In many parts of the United States, indirect injury to container-grown plants is more the norm than an exception. Many researchers have conducted experiments to determine root-zone temperatures that cause indirect injury. In general, a 104°F root-zone temperature for 5 to 6 hours per day can impair or damage the physiological processes of most of the plants studied. Based on research, growers should strive to always maintain root-zone temperatures below 108° to 113°F, and chronic, longer exposures below 100°F to 104°F.

Factors That Influence Root-zone Temperature Fluctuations

Root-zone temperature extremes vary with location in the container substrate (growing medium). Major factors that affect temperature patterns in outdoor nursery containers include time of day and season of year, geographic location, composition of the substrate, irrigation practices, container size and spacing, as well as the material and color of containers. The figure below illustrates the normal temperature fluctuations in a black #2 container on a sunny day in July/August in the southeastern U.S.

The maximum root-zone temperatures within a container occur in various locations or quadrants of the container profile throughout the day. The root-zone temperatures adjacent to the east container wall increase dramatically as soon as sunlight strikes the container wall in the morning. Temperatures in the south quadrant reach their highest temperature close to solar noon. The west quadrant is shaded from direct sunlight until solar noon, and highest temperatures will occur during the mid- to late afternoon.

Heat concentrates more slowly in the north and center quadrants of the container, and temperatures in these quadrants are highest during late afternoon and early evening, although these maximum temperatures are lower than the maximum within the other quadrants. With larger containers one would expect similar temperature patterns near the container walls, but the temperatures near the center of the container would be lower than in #2 containers, being buffered by the distance the heat would have to move through the substrate. Regardless of container size, growers should anticipate that root-zone temperatures near the east, south, and west walls of unshaded black polyethylene nursery containers can cause direct and/or indirect injury to many nursery plants on sunny days throughout most of the year.

Black polypropylene nursery containers act as solar collectors, as do the surrounding surfaces. Radiant heat energy enters the container system primarily

Table 1. Predicted critical temperatures (°F) causing direct membrane damage for excised roots of selected plants after a 25- to 35-minute exposure

Plant	Predicted critical temperature (°F)
Acacia smallii	114
Acer rubrum	127
Acer × freemanii	127
Cephalanthus occidentallis	124
Cercidium floridum	121
Citrus aurantium (Sour orange)	126
C. x sinensis X Poncirus trifoliata (Carrizo citrange)	125
C. paradisi × P. trifoliata (Swingle citrumelo)	128
Dracaena marginata ' Tricolor'	136
Ilex vomitoria ' Schilling's Dwarf'	127
Ilex crenata 'Helleri'	124
Ilex crenata 'Rotundifolia'	118
Ilex cornuta 'Dwarf Burford'	116
Illicium parviflorum	123
Ixora coccinea	132
Juniperus chinensis 'Parsonii'	119
Magnolia grandiflora 'St. Mary'	126
Musa sp. 'Grand Naine'	128
Nyssa aquatica	124
Pittosporum tobira	126
Salix nigra	114
Taxodium distichum	116

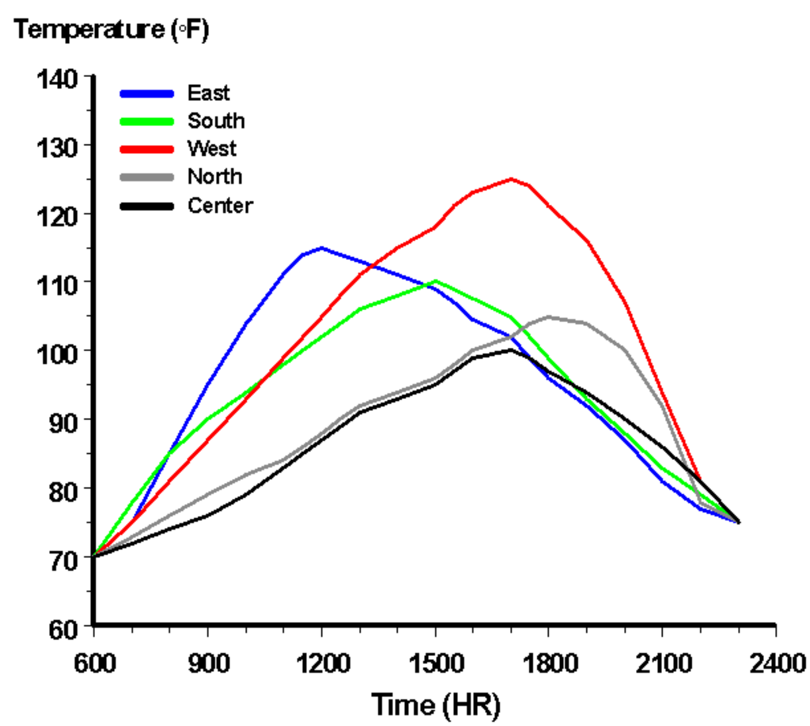

Figure 1. Root-zone temperature fluctuations 1 inch from the sidewall in the east, south, west, and north quadrants and in the center of the substrate in a #2 container throughout a mid-summer day in Lexington, Kentucky

from direct and reflected sunlight. Heat energy also moves by conduction and/or convection. Conduction of heat occurs by the movement of heat energy from one material to the other when in direct contact. The rate of movement (thermal conductivity) is affected by the type of materials and the difference in temperature between them. Convection describes heat energy movement through the air and is impacted by the difference in temperature between two air masses and the degree of air circulation. Heat is transferred within the container primarily through conduction and to the external environment via convection, solar radiation, and the heat of evaporation (evaporative cooling). Interestingly, air temperatures during the growing season have limited impact on the temperature profiles of container substrate in outdoor production nurseries because radiant heat transfer from sunlight is such an overwhelming source of heat gain.

In models used to describe heat flow in containers, the parameters include the incidence of solar radiation striking the side of the container throughout the day, the absorption and reflectivity of solar radiation by the container surfaces, wind speed and atmospheric humidity of air surrounding the container, and the thermal properties of the substrate over a range of moisture contents. These models have been used at locations throughout the United States to simulate the dynamic movement of heat through the substrate in containers of various volumes and shapes. This information may be used to predict temperatures at any location within the container profile at any time of day throughout the year.

We found that the intensity and direction of solar radiation incident on all container surfaces had the greatest impact on root-zone temperature fluctuations within the container profile. In contrast, wind speed and atmospheric humidity had minimal impact on root-zone temperatures.

The container quadrant receiving the most intense solar radiation differs not only with time of day but also time of year as illustrated in Figure 2. The **solar altitude** is the angle of the sun relative to the earth's horizon. **Equinox** is the time when the plane of the earth's equator passes through the sun's disk, i.e. when sunrise is due east and sunset is due west, which occurs twice per year (March and September). **Solstice** occurs twice each year (summer solstice June 21 and winter solstice December 22) when the sun rises and sets farthest north of east-west and south of east-west, respectively. The **declination angle** is the angular distance of the sun north or south of the equator due to the fact that the earth has an axial tilt of 23.5º relative to the sun. In northern states, critically high container root-zone temperatures can occur from late spring to early fall, but the location of the maximum temperatures within the container substrate profile shifts throughout the season.

In Kentucky, the highest container root-zone temperatures typically occur from late August through early October, despite cool air temperatures, because of clear, sunny days and the lowering declination angle of the sun. The declination angle of the sun from the horizon and solar altitude are lowest during late fall and early winter. In nurseries across the United States, heat-induced root injury can occur in the southern quadrant of unprotected containers during this time. The northern quadrant of containers is generally coolest throughout the year because the north container wall receives the least direct solar radiation during a production cycle.

Roots might recover from exposure in one quadrant only to be injured in another quadrant by extreme temperatures as the season changes (Figure 3). There is also potential for root injury in container-grown plants that are moved from the container nursery to a landscape site or a retail establishment where they are repositioned and the northern side of the container is exposed to sunlight for even a short period of time. This problem is also of concern for plants produced in the pot-in-pot production system where roots are protected on all sides from solar radiation during the production cycle and may be susceptible to root damage from direct sun on the container wall.

Reducing High Root-zone Temperature

Because direct solar radiation on container sidewalls is the primary driver of heat stress in container-grown plants, anything nursery growers can do to reduce the incidence of sunlight on container sidewalls will help lower high root-zone temperatures. Obviously, growing plants under shade will limit the exposure of container sidewalls to direct solar radiation, but this practice might not produce some plant species of the desired quality in an economically feasible timeframe.

Container color and surface smoothness have an impact on root-zone tem-

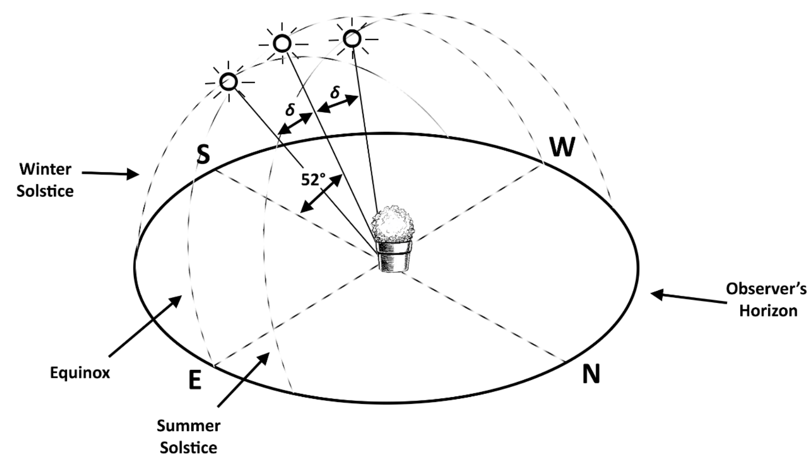

Figure 2. The direction and intensity of direct solar radiation striking a container sidewall varies throughout the day and time of year. (Lexington latitude = 38°; solar angle during equinox = 52°; tilt angle (δ) = 23.5°). Illustration by Joshua Knight

Figure 3. Regrowth of roots on one side of the container and death of roots on the other side as the sun angle changes with the season

peratures. The color and smoothness of a surface determines the portion of the sun's energy striking the container sidewall that is reflected or absorbed. Rough surfaces and light-colored surfaces reflect a higher portion of incipient sunlight than smooth, dark surfaces. Researchers have shown that under full sun the substrate inside of white, green, yellow, silver, or light blue containers can be 9 to 18°F cooler than inside black containers. However, keep in mind customer preference. In many cases, consumers prefer black or green containers. Light-colored containers might also degrade and become brittle in direct sunlight sooner than black containers because of the sun's ultraviolet radiation. Growing plants under shade will reduce or eliminate the effect of container color on root-zone temperature.

Container material also impacts temperature but generally less than container color or surface smoothness. Thick, paper containers or fiber pots absorb and conduct less radiant energy than plastic or metal containers. Maximum temperatures in fiber containers are often as much as 18°F lower than conventional black plastic containers and result in increased shoot and root growth for many plants. This occurs because these fibrous materials do not conduct heat very well. They are a good insulator of heat movement.

As stated earlier, maximum daily temperatures at the center of the container profile are generally lower and occur later in the day as container volume increases. This is a function of the distance that heat energy must be transferred through the container profile. Therefore, large containers can have a greater portion of a plant's root system exposed to moderate or more ideal temperatures than small containers, at least until the roots reach the wall interface of the larger container. Researchers have shown that for some landscape plants such as southern magnolia (*Magnolia grandiflora*) the time required for young plants to grow to marketable size is less if they are shifted to larger container volumes earlier in the productions cycle or if they are grown entirely in the container size in which they will be marketed. Using larger container volumes to increase carbon assimilation and plant growth might be even more important during late spring and early fall, when daily maximum air temperatures are lower. The lower solar declination angle in spring and fall increases the number of hours per day of direct sunlight on container sidewalls. Container spacing for mutual shading of container sidewalls and insulating the containers on the outside of blocks of plants in some way can be effective, especially in the spring and fall. Although practices such as placing the outside row of plants into larger containers to shield them from radiation or placing containers without plants in outside rows will reduce space use efficiency, such practices can reduce root injury in these seasons. Placement of a reflective material around perimeter plants in the block can also be effective.

Container shape can influence heat load, but only if the amount of direct solar radiation is affected. Short, wide containers with a higher ratio of container volume to container wall height will result in less heat absorption. "Squat" pots then can be an alternative for shallow-rooted, heat sensitive plants such as azalea. Also, the tilt angle of the container wall can be important in this regard. A model of temperature flows in containers in Phoenix, Arizona, and Lexington, Kentucky, shows that as container height decreased, the container wall tilt angle necessary to lower the temperature at the center of the substrate to at least 104°F increased. However, container manufacturers and retailers have been reluctant to change the container wall tilt angle for modest reduction in maximum root-zone temperature.

Any cultural practice or system design that reduces the direct or reflected solar radiation on the container sidewall will reduce the heat load. The vast majority of heat load comes from direct solar radiation; however, a highly reflective ground cover such as white shell or gravel was shown to increase the root-zone temperature at the container sidewall by 4 to 8°F in Texas compared to a black woven polypropylene fabric surface.

Plants grown in containers are usually placed on beds covered with a plastic fabric or gravel to conserve space. One method used to reduce solar radiation on container walls is to space containers close together to provide mutual shading. Delaying the spacing of containers until required by crowding of the foliage canopy can reduce substrate temperatures. Spacing of plants before the shoot growth can provide mutual shading or following heavy pruning in late spring or early summer can result in temperatures along the sidewall sufficient to kill roots of unacclimated plants. The arrangement of spacing, i.e. rectangular or triangular spacing, can impact temperatures in containers if the canopies are large and thick enough and the spacing close enough to shade the western and/or southern exposures of containers. One note of caution though: When plants reach a size where they are competing for light and are close to touching, they are often moved farther apart, exposing container walls to direct radiation. Plants are sometimes pruned at that time as well, which further reduces mutual shading, and container sidewalls that were previously shaded by adjacent containers are exposed to sunlight. Root injury has been frequently noted in such circumstances.

Containers shielded from direct solar radiation by overhead shade, by a reflective cover over the container sidewall, or by inserting the production container in a larger container can reduce the heat load on containers and therefore reduce root-zone temperature to near ambient air temperature. Development of aboveground and belowground "pot-in-pot" systems were initiated primarily to address the impact of high root temperatures in container-grown plants and also to reduce occurrence of container "blow over." Such shielding drastically lowers root-zone temperature fluctuations and extremes in summer or winter. Placing the production container inside another container large enough to provide insulating effect of an air space reduces absorption of solar radiation drastically. The greatest impacts come from burying the protective "socket" container in the soil, but aboveground pot-in-pot systems also lower container substrate temperatures. Temperature fluctuations and extremes are greatest in a conventional container production system, at intermediate levels for aboveground pot-in-pot systems, and least for in-ground pot-in-pot systems.

Container substrates consist of composted organic residues such as pine bark or other wood industry byproducts. Sand or small gravel is often blended to add weight to stabilize the containers and improve infiltration of water. The amount of air space in a substrate as well as the amount of water-filled space in and between particles can impact the velocity of heat flow within the container profile. In general, fast-draining, lightweight substrates with high air-filled porosity conduct heat poorly from the container wall to the center quadrant of the container profile compared with heavier substrates that retain more water.

There are only minor differences in the temperature of a range of organic substrates. Most of those differences relate to the balance between water and air in the pore space after irrigation and

Figure 4. Red maple in a belowground pot-in-pot system. Image by Dr. Amy Fulcher

Figure 5. Aboveground pot-in-pot with shielding container anchored to the ground or with a wide base for stability

drainage. For example, at a volumetric water content of 10 percent, there is little difference in the rate of temperature change in a pine bark medium with varying ratios of sand up to 40 percent by volume. The relatively high water content probably connects particles to each other and provides a path for heat flow. Below the 10 percent water content, heat energy moves more slowly through the substrate as airspace between particles serves as insulation.

Irrigation has been suggested as a means to reduce the rate of temperature increase and the maximum daily temperature in containers. Results of field experiments revealed that to effectively cool the root zone in a #3 container would require a midday application of at least 3 quarts of water at 79°F. That volume of irrigation was almost three times the water holding capacity of most commercial substrates. Lower volumes of irrigation cools the surface of the container but can actually increase the temperature in the center of the container. It appears the heat from the top portion of the substrate is transferred to the center of the container. In other words, it takes a high volume of water to "flush" heat from a container. These results do not support the practice of "syringing" container-grown plants with a relatively small volume of water in an attempt to lower root-zone temperature.

The presence of cool water in the pore space at the beginning of the day can buffer temperature change somewhat. Therefore, timing of irrigation can have an impact. Predawn irrigation compared to afternoon irrigation results in slightly lower maximum daily temperature in the substrate. Irrigating throughout the day, i.e. cyclic irrigation, can result in slightly lower maximum temperatures. Higher temperatures can increase evaporative loss and result in the need for more frequent irrigation.

Post-production handling must also consider solar radiation on container sidewalls and water management. Even a 30-minute exposure of a container sidewall to direct sunlight can result in temperatures that cause direct injury to plant roots near the interface of the substrate and container. Therefore, plants with roots concentrated near a container's sidewalls are more susceptible to such injury. Plants being held on asphalt drives or parking lots before being planted or moved to more appropriate holding or display areas raises concern about root injury and plant health after marketed and/or planted in the landscape.

Summary

- Root-zone temperatures in containers are routinely above optimum during the summer months.
- Temperatures in containers high enough to kill roots occur daily in summer months and can occur at other times of year too.
- The temperature fluctuations in containers vary with time of day and time of year. Substrate temperatures adjacent to the container sidewall will be highest in east and west quadrants and can be high enough to damage roots in the south quadrant during spring and fall.
- Direct solar radiation on the container sidewall is the primary source of such heat in the root zone, so anything one can do to minimize that direct solar radiation will lower the temperature. This includes such things as:
  - Use reflective or light colored containers.
  - Produce plants under shade in certain situations.
  - Space containers for mutual shading.
  - Select container shapes that reduce the sidewall angle or decrease the container wall surface-to-container volume ratio.
  - Place container-grown plants inside a socket pot to insulate from direct solar radiation. The socket pot can be aboveground or partially inserted in the ground.
  - Grow plants in larger container sizes.
  - Avoid post-production handling that exposes container sidewalls to direct solar radiation, especially for plants with a concentration of roots near the container and substrate interface.
- Water management can lower maximum daily temperature somewhat.
  - Early morning irrigation can lower the maximum daily root-zone temperature somewhat but alone may not reduce the temperatures enough to eliminate stress.
  - Cyclic irrigation can have a limited impact on maximum daily temperature.

Additional Information

For a thorough review of research on reducing heat stress to container-grown plants:

Ingram, D.L., J. Ruter, and C.A. Martin. 2015. Review: Characterization and impact of supraoptimal root-zone temperatures in container-grown plants. HortScience 50:530-539. http://hortsci.ashspublications.org/content/50/4/530.full.pdf+html