Plant Heat Stress and Its Management
by Thomas D. Landis

Temperature is one of the most critical of the growth-limiting environment factors in nurseries, because it controls all aspects of plant metabolism and growth. Plants have adapted to a discrete range of temperatures. For instance, 6 conifer and broadleaved tree seedlings grew best in the relatively narrow range of 66 to 73 ^{o}F (19 to 23 ^{o}C). During the sunny and hot days of summer, temperatures can often exceed these ideal temperatures. This article will identify the types of heat injuries that can occur to nursery stock, and discuss the most practical cultural methods for preventing them.

Stress physiologists recognize 2 types of heat injury (Levitt 1980):

- Direct heat injury occurs when plant tissues are harmed by excessive temperatures, causing cell membranes to rupture and walls to collapse. In the case of young plants and succulent tissue, direct heat injury can cause severe growth loss or even death. In nature, heat injury is limited to young first-year plants but can occur on much larger nursery stock due to their accelerated growth rates and propagation method.

- Indirect heat injury refers to a number of metabolic maladies such as the denaturation of proteins that occur at above optimum temperatures (Hermann 1990). The symptoms of indirect heat injury are less obvious and can vary considerably between plant species and growth stages. Succulent, actively growing plants are much more susceptible to indirect heat stress than dormant, hardy plants.

Heat injuries in forest and conservation nurseries.

In nurseries, excessive heat can occur during spring or summer when sunlight is most intense and young plants are germinating or actively growing. With proper irrigation, plant foliage is continually cooled by transpiration and so should not be subject to heat injury (Figure 1). This is true even on outplanting sites without the benefits of irrigation. For example, foliage temperatures of outplanted Douglas-fir seedlings were within 5 ^{o}F (3 ^{o}C) of surrounding air temperatures (Helgerson 1990).

Stems and roots are not so protected, however, and can suffer direct heat injury. Two different types of heat injury have been reported in nurseries:

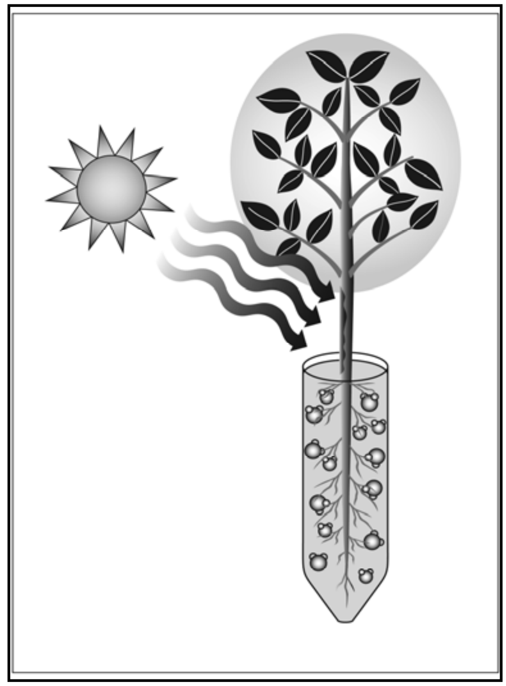

Figure 1 - Because of the frequent irrigation in nurseries, plant foliage is cooled by transpiration . However, stems of young plants can be damaged by intense sunlight because protective bark has not yet developed.

1. Solar heat injury to stems of young plants - Because it takes time to develop protective bark layers, the stems of young plants can be damaged by intense sunlight (Figure 1). The problem was first reported with conifer germinants in both natural regeneration and in nurseries (Hartley 1918, Baker 1929).

Symptoms - Injury usually occurs on the stem just above the soil surface where the buildup of heat is greatest (Figure 2A). Numerous studies found that injury typically occurs at temperatures between 117 to 151 ^{o}F (47 to 66 ^{o}C) which have been documented in nurseries (Helgerson 1990). With young germinants just emerging through the soil or seed covering, injured seedlings appear constricted (Figure 2B) due to the collapse and rupturing of the stem cells. On older seedlings, a white spot may develop on the south or southwestern side of the stem (Figure 2C). In greenhouse experiments using heat lamps, seedlings were able to recover if the cellular damage did not reach the vascular tissues (Smith and Silen 1963).

Note that germinants can be killed before or just after emerging from the soil, and these losses are often misdiagnosed as damping-off. True damping-off is a fungal disease which can be distinguished from heat injury

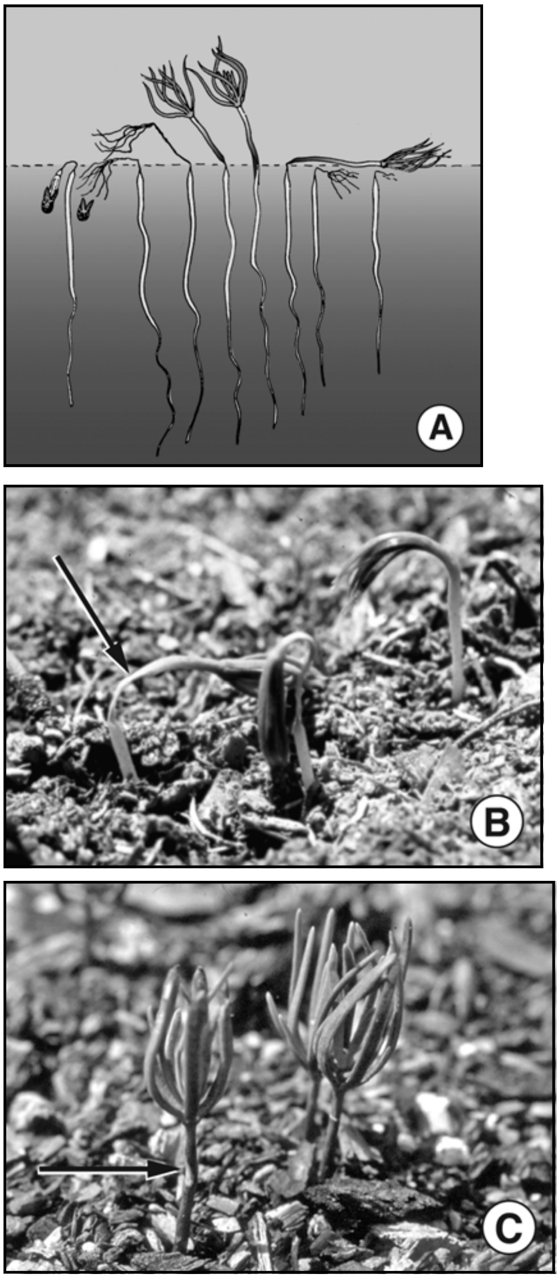

Figure 2 - Intense sunlight can cause damaging surface soil temperatures resulting in "heat damping-off" (A). Dark organic seed mulches build-up heat rapidly and the heat can kill young germinants (B), and cause white lesions on older seedlings (C).

because the roots of affected seedlings are brown or black and decayed. Roots of heat injured seedlings remain white below the constricted area (Figure 2A).

Management - Because water has the highest latent heat of vaporization of any liquid, heat injury can be prevented by keeping the surface of seedbeds and containers moist with frequent light irrigations.

Container nursery managers should schedule short bursts ("mists") of irrigation during the hottest time of day. This "water shading" is particularly effective during the establishment phase, when the young, succulent germinants can be easily damaged by high temperatures at the surface of the growing medium. Mist cooling can also supply the young seedlings with enough water without saturating the medium. Some container nurseries have outfitted their moveable irrigation booms (Figure 3A) with multiple-position nozzles that contain a mist head in addition to the standard irrigation nozzle. Older seedlings can also be cooled with irrigation, but this is usually done on a periodic basis to supplement the standard greenhouse cooling system during unusually hot weather.

In bareroot nurseries, the decision of when to irrigate and for how long will depend on the plant species and soil type. Some nurseries irrigate 5 to 10 minutes during every hour the temperature is above that considered critical; others water for an hour; and still others water until the soil temperature drops below a fixed, safe temperature [for instance, 77 °F (25 °C)]. Some bareroot nurseries use air temperature as a guide for determining the need for cooling, but the majority use soil surface temperature, usually measured 0.5 to 1 cm below the surface (Table 1).

Covering seeds with light-colored mulches can be effective in reflecting sunlight (Figure 3B). Dark mulches can increase damage because they absorb solar energy but are also poor conductors which allows heat to build up at the soil surface. When surface temperatures were monitored under dark-colored forest sand and light-colored granite grit (Peterson and Tuller 1987), the highest temperatures were recorded under dark mulch at 108 °F (42.5 °C). Unfortunately, I can vouch for this by personal experience because once we covered Engelmann spruce (*Picea engelmannii*) seeds at Mt. Sopris Nursery with a dark mulch thinking that the dark color would speed germination. Instead, the intense sunlight at 6,400 feet of elevation damaged many of the germinating seedlings (Figure 2B**)**. As the old saying goes: "we get too soon old, and too late smart".

Heat tolerance of nursery stock can be increased by prior exposure to hot but non-lethal temperatures. Black spruce (*Picea mariana*) container seedlings that were preconditioned to 100 °F (38 °C) for only 3 hours per day for 6 days were significantly more heat tolerant than non-conditioned stock (Colombo and Timmer 1992). This relatively brief heat treatment reduced both direct

Table 1 - Guidelines for When to Irrigate Seedbeds to Prevent Heat Injury*		
Time Period	**Do Not Exceed Surface Soil Temperature**	
Before July 1	90 °F	32 °C
July 1 to August 1	95 °F	35 °C
August 1 to September 1	100 °F	38 °C
After September 1	105 °F	41 °C
*modified from Thompson (1984)		

and indirect heat injury (Figure 4). This reinforces the need to gradually expose nursery stock to hot temperatures before the "dog days" of summer, and especially to include a period of heat exposure when hardening plants before harvest and outplanting.

2. Solar heat injury to roots of container stock - The roots of container plants grow best just inside the walls where both water and air are most readily available. Unfortunately, this also makes them susceptible to heat injury. Roots have adapted to the buffered temperatures of native soil and therefore cannot tolerate excessive heat.

Symptoms - Heat injury to container plant roots can occur anywhere during clear weather because the damage comes from solar radiation, not air temperatures (Figure 5A). Because of their solar exposure, plants along the southern and western edge of container blocks are most susceptible. In standard black plastic containers, growing medium temperatures can easily reach temperatures high enough to cause injury (Newman 1987). Growing medium temperatures as high as 138 °F (59 °C) have been recorded in southern nurseries and even in Ohio. Even in the relatively mild Pacific Northwest, container media temperatures of 122 °F (50 °C) have been observed (Mathers 2001). Note that these studies were done on larger volume containers where the heat can be better dissipated by the greater amount of growing media. Although little research has been done, the risk of heat injury would be much higher on smaller containers (Figure 5B).

One of the real risks of high growing medium temperatures is increased damage from root pathogens. Temperature affects both the incidence and severity of conifer seedling root rot from *Fusarium oxysporum*. Mortality of Douglas-fir container seedlings was four times greater when growing medium temperatures exceeded only 74 °F (23 °C) (Strobel and Sinclair 1991). In an-

Figure 3 - Cooling the surface of containers is easier with irrigation booms equipped with a mist nozzle (A). Light-colored seed coverings (B) also help reflect solar radiation.

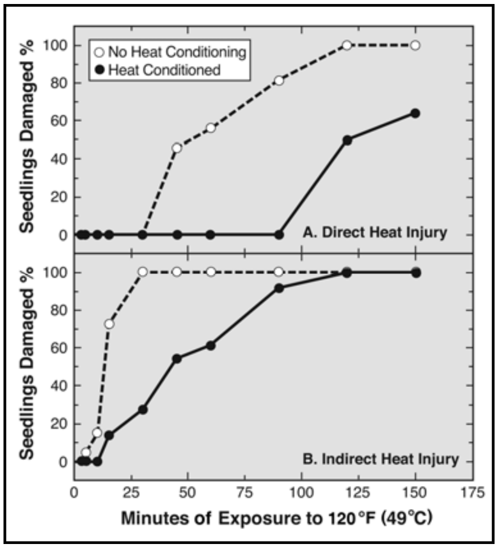

Figure 4 - Seedlings that were preconditioned to hot temperatures were better able to tolerate damaging heat levels (modified from Colombo and Timmer 1992).

other study with *Eucalyptus* spp. seedlings, the pathogenic root fungus *Phytophthora cinnamomi* was most damaging at temperatures of 64 to 72 °F (18 to 22 °C) where large numbers of highly infectious zoospores are produced (Halsall and Willams 1984).

Management - The best way to prevent solar heat injury to container plant roots is to always keep the growing media wet. In container nurseries, shading is also recommended especially during seed germination and emergence before plant canopies develop and provide self shading (Newman and Davies 1988).

Container type and color must also be considered. Black plastic absorbs the most sunlight resulting in growing medium temperatures high enough to cause root injury or even death (Whitcomb 1980). The growing medium in white containers has been shown to be cooler than black ones, which can be especially important in small volume plug trays (Faust and others 1997). Container composition can also help protect against heat injury. Styroblock® containers are ideal because the white color reflects light and the styrofoam walls provide good insulation. Jiffy containers or fiber pots keep root systems cool because evaporation is continually cooling the outside of the container (Mathers 2001).

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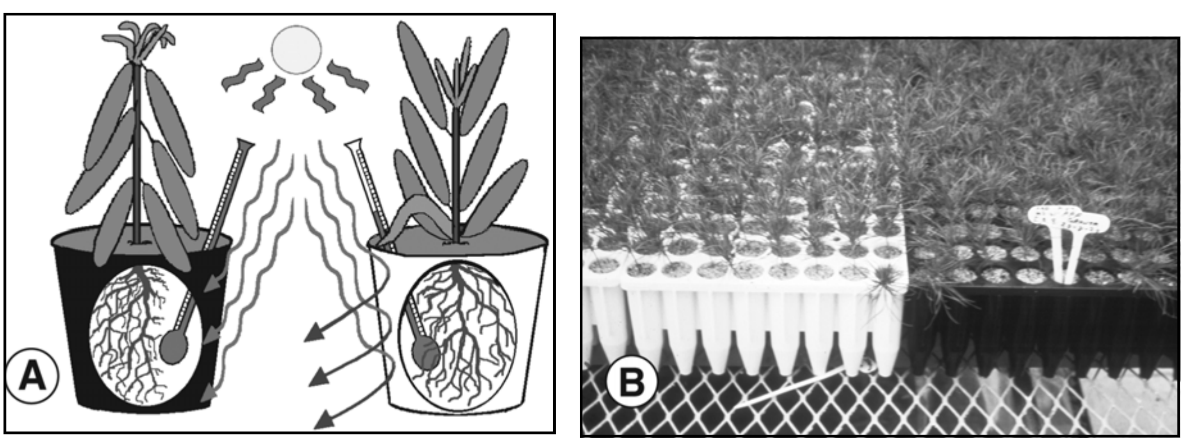

Figure 5 - The growing media in containers exposed to direct sunlight can quickly reach damaging temperatures and black absorbs more radiation than white (A). The risk of injury is even greater in smaller volume containers especially during seed germination (B).

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