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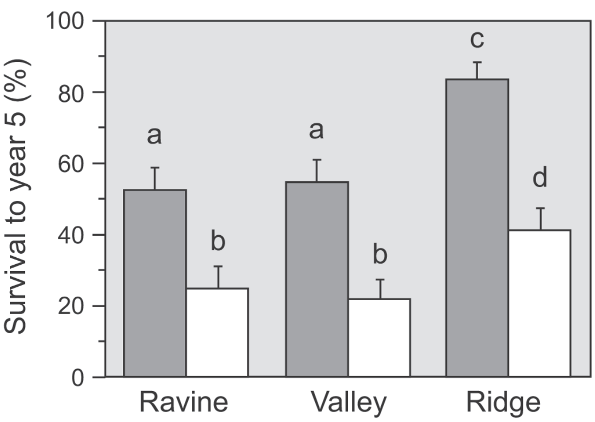

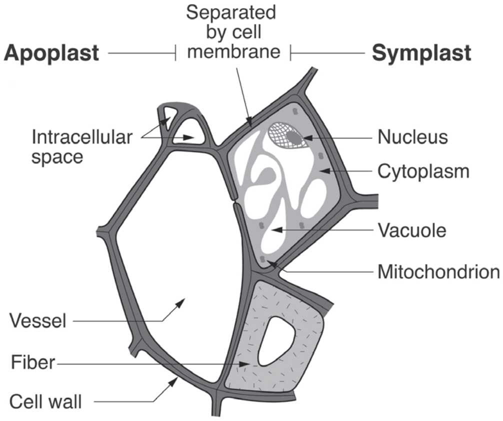

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Frost protection with irrigation: taking another look

by Thomas D. Landis, Nabil Khadduri, and Diane L. Haase

1. Introduction

Irrigation is used in temperate zones throughout the world to protect high-value crops against damaging cold temperatures. It is estimated that 5 to 15 percent of the total world crop production is affected by cold injury each year (Evans and van der Gulik 2011). Although growers have used irrigation to protect their stock for almost a century, some new and practical information has recently come to light.

Sprinkler irrigation can protect sensitive crops from freezing temperatures because of the high latent heat of fusion of liquid water (Figure 1). For every 1 gallon (3.8 L) of water that freezes into ice, 144 British Thermal Units (BTU) of heat are released and it is this heat that protects the plants. Likewise, 972 BTU of heat must be supplied to change 1 gallon (3.8 L) of liquid water into water vapor (Schroeder and Buck 1970). This latent heat of vaporization can actually increase the cold injury to plants if sprinkler irrigation is applied unevenly or is stopped before the ambient temperature rises above freezing because water evaporation of actually drives temperatures below ambient conditions.

2. Frosts versus Freezes

Two types of cold-weather injury can be damaging in forest, conservation, and native plant nurseries: advection freezes (when a cold air mass moves into an area) and radiation frosts (when heat is lost from an area). Advection freezes happen after cold fronts introduce large subfreezing air masses that affect large regions; radiation frosts, on the other hand, occur on clear cold nights and typically affect relatively small areas ("frost pockets").

During any kind of cold-weather injury, four weather elements come into play: temperature, humidity, wind, and cloud cover.

2.1 Temperature

The terms frost and freeze are often used interchangeably to describe injury cased by temperatures below 32°F (0°C). Plants cool in relation to ambient temperatures and damage occurs when ice forms within their tissues. The critical temperature at which plant tissues are damaged by cold is known as cold hardiness, and varies by species, ecotype, season, and type of tissue.

So, what happens inside plant tissues when they freeze? Cells are enclosed by flexible walls made primarily of cellulose, which is stiff and strong. Living cells that function in photosynthesis and other physiological processes are filled with cytoplasm, which is surrounded by a semipermeable membrane composed of a fatty material called lipid in which protein molecules are embedded. This membrane plays a key role in plant cold hardiness; everything within the membrane is referred to as symplast and is living tissue. Everything outside this membrane (cell walls, vessels, intercellular spaces, empty cells, etc.) is referred to as apoplast and is not living (Figure 2A).

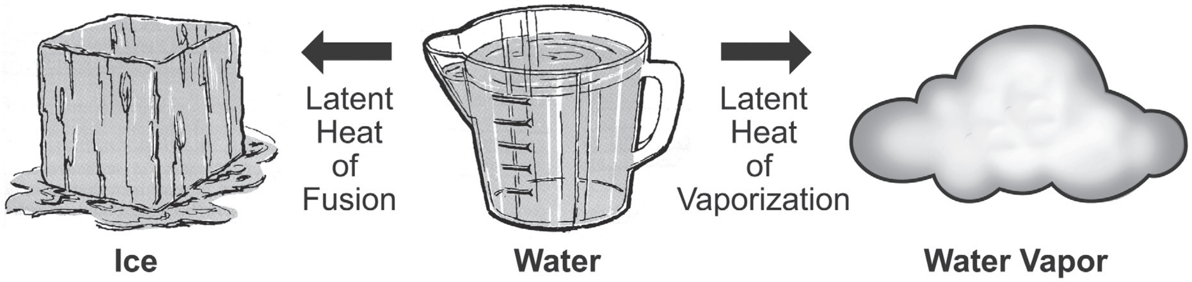

Figure 1 - Frost protection with sprinkler irrigation depends on the energy released or absorbed when water changes from one physical state to another. When water freezes into ice, each pound of water releases 144 BTU of heat (latent heat of fusion). To change one gallon of liquid water to water vapor requires much more heat: 972 BTU (latent heat of vaporization) (modified from Schroeder and Buck 1970).

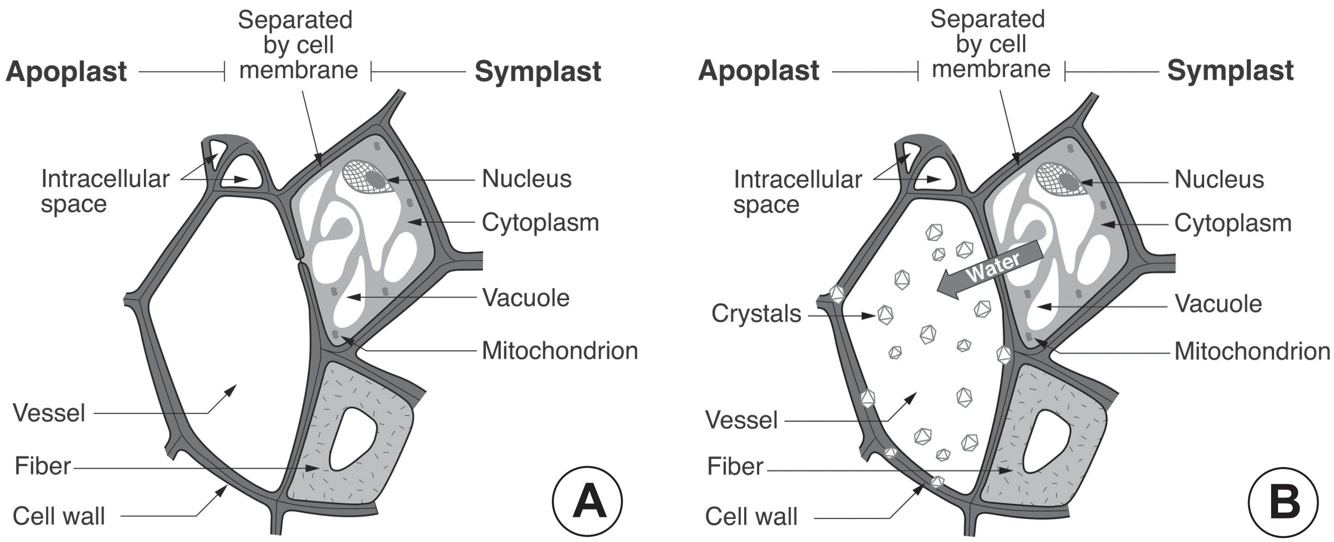

Figure 2 - The water in living cells (symplast) has a lower freezing point than the purer water in nonliving cells (apoplast). The symplast is separated from the apoplast by a cell membrane (A). When temperatures fall below freezing, ice crystals begin to form in the apoplast. As these crystals grow (B), they can rupture cell membranes and cause dehydration of the symplast (Ritchie and others 2010).

Both the symplast and apoplast contain some water. Apoplast water is nearly pure, so its freezing point is close to 32 °F (0 °C). In contrast, the symplast contains dissolved sugars and salts, suspended starch granules, and protein molecules. These solutes act as “antifreeze,” depressing the freezing point of the symplast to considerably below freezing. When cells are exposed to sub-freezing temperatures, the apoplastic water begins to freeze. As it does, small ice crystals form within the cell walls, intercellular spaces, and other voids within the apoplast (Figure 2B). The symplast water, with its lower freezing point, resists freezing. Therefore, the ice that forms within the plant tissue is contained in the apoplast and does little or no damage.

Ice, however, has a very strong affinity for water – so strong that ice crystals pull water tenaciously across the membrane and out of the symplast. Because the membrane is permeable only to water, the dissolved sugars and other materials remain in the symplast even as water is drawn out. This raises the concentration of the dissolved solutes, further lowering the freezing point of the symplast water. When plant tissues are not cold hardy, or when the temperature falls below the plant tissues’ seasonal level of hardiness, the cytoplasm can become severely dehydrated. Thus, plant tissue can be damaged by cold temperatures or by the resultant desiccation. In severe freezes where the temperature drops rapidly, direct cold injury is more common compared with more gradual freezes that lead to cell desiccation (Ritchie and others 2010)

2.2 Humidity

The amount of water in the air has a significant effect on cold injury to crops. The dew point is the temperature at which water vapor in the air condenses, and can be measured as the wet bulb temperature, which is very close to the actual dew point. The importance of the dew point is often not appreciated, but it is the single most important weather factor in frost protection. High dew point temperatures are beneficial because the high humidity retards heat loss by radiation, whereas low dew points are extremely detrimental because the low humidity increases evaporation from plant surfaces and drives their temperatures even lower (Evans and van der Gulik 2011). Therefore, growers should monitor atmospheric humidity by means of dew points or wet bulb temperatures before and during frost events; this information is provided by most weather services or can be easily measured in nursery weather stations.

2.3 Wind

Advection freezes are characterized by lateral movement of large subfreezing air masses (cold fronts) driven by winds more than 5 mi/h (8 km/h)(Evans and van der Gulik 2011). Wind also increases evaporative cooling when dew points are low and thereby increases cold damage to crops.

2.4 Cloud cover

Radiation frosts occur on clear cold nights with little or no wind. Because plants and other objects radiate heat into a colder environment in proportion to their relative temperature differences, crops will lose heat at a faster rate when exposed to a clear night sky, compared with much slower heat loss rates under cloudy conditions (Evans and van der Gulik 2011).

3. Types of cold weather injury

Two types of cold weather injury can occur in forest, conservation, and native plant nurseries (Table 1), and irrigation can protect against both. Cold injury is the most common type of overwinter injury, and is caused by sudden cold or frosts. It can happen almost anywhere during unseasonably cold weather, and any succulent or meristematic tissue can be injured: shoot tips and bud meristems (Figure 3A) as well as the lateral cambium (Figure 3B). Although roots are insulated by soil in bareroot crops, the exposed roots of container plants are especially susceptible to cold injury. Roots do not harden very much and so can be damaged by minor freezing events, especially if they last for an extended period. Frost damage is especially common on species that are not native to the area. Cold injury is directly linked to seedling hardiness and dormancy so cultural treatments to stop shoot growth and increase tissue hardiness, such as late-summer moisture stress and nutrient management, can minimize damage. Symptoms of cold injury typically develop within a few days and damaged tissue can be diagnosed with a cut that exposes browned tissue (Haase 2011).

Winter desiccation ("winter burn") occurs when soils or growing media are frozen (Figure 3C) and nursery stock is subjected to extended periods of clear sunny weather. Winter burn is most common along the downwind side of mountains during warm and windy weather such as foehn or chinook winds (Figure 3D). Winter desiccation can even occur in normally wet climates such as western Washington and Oregon during atypical strong east winds (Moore 2014). Because of their relatively small volume of roots and lack of soil buffer, container plants are much more susceptible to this type of injury. Winter desiccation is not related to seedling hardiness or dormancy so protection is the only option. Symptoms of winter drying are slower to develop than cold injury, usually requiring weeks rather than days.

3.1 Cold hardiness

Cold hardiness refers to the ability of a plant tissue to withstand injury from below-freezing temperatures, and varies among species, ecotypes, and different plant tissues. The shoots of boreal conifers, such as black spruce (*Picea mariana*), white spruce (*P. glauca*) and jack pine (*Pinus banksiana*) can tolerate extreme cold during their period of maximum hardiness, and have been tested down to -112 °F (-80 °C). Due to climatic similarities, many Rocky Mountain conifers, such as lodgepole pine (*P. contorta*) and Engelmann spruce (*P. engelmannii*), can also tolerate extreme winter cold (Figure 4). Species at lower elevations, especially species with indeterminate shoot growth such as coast redwood (*Sequoia sempervirens*) and western redcedar (*Thuja plicata*) rarely acclimate to temperatures below -20 °C (-4 °F). Indeteriminate species are also much more prone to dehardening following periods of unusually warm winter weather. Interestingly, cold tolerance of wide-ranging species, such as Douglas-fir (*Pseudotsuga menziesii*), vary tremendously by ecotype; low elevational coastal ecotypes in Washington State can tolerate -4 °F (-20°C) whereas high elevation sources in Montana can tolerate -22 °F (-30 °C)(Ritchie and others 2010).

Table 1 - Comparison of types of overwinter injury in nurseries

Type of injury	Caused by	Symptoms	Species affected	Stocktypes affected	Related to seedling hardiness or dormancy
Cold injury	Unseasonably cold air temperatures	Meristems most affected: buds and shoot tips, lateral cambium, root	All species, especially non-natives	Bareroot and container	Yes
Winter burn	Frozen soils and drying winds	Only exposed foliage affected	Conifers	Bareroot, and especially container	No

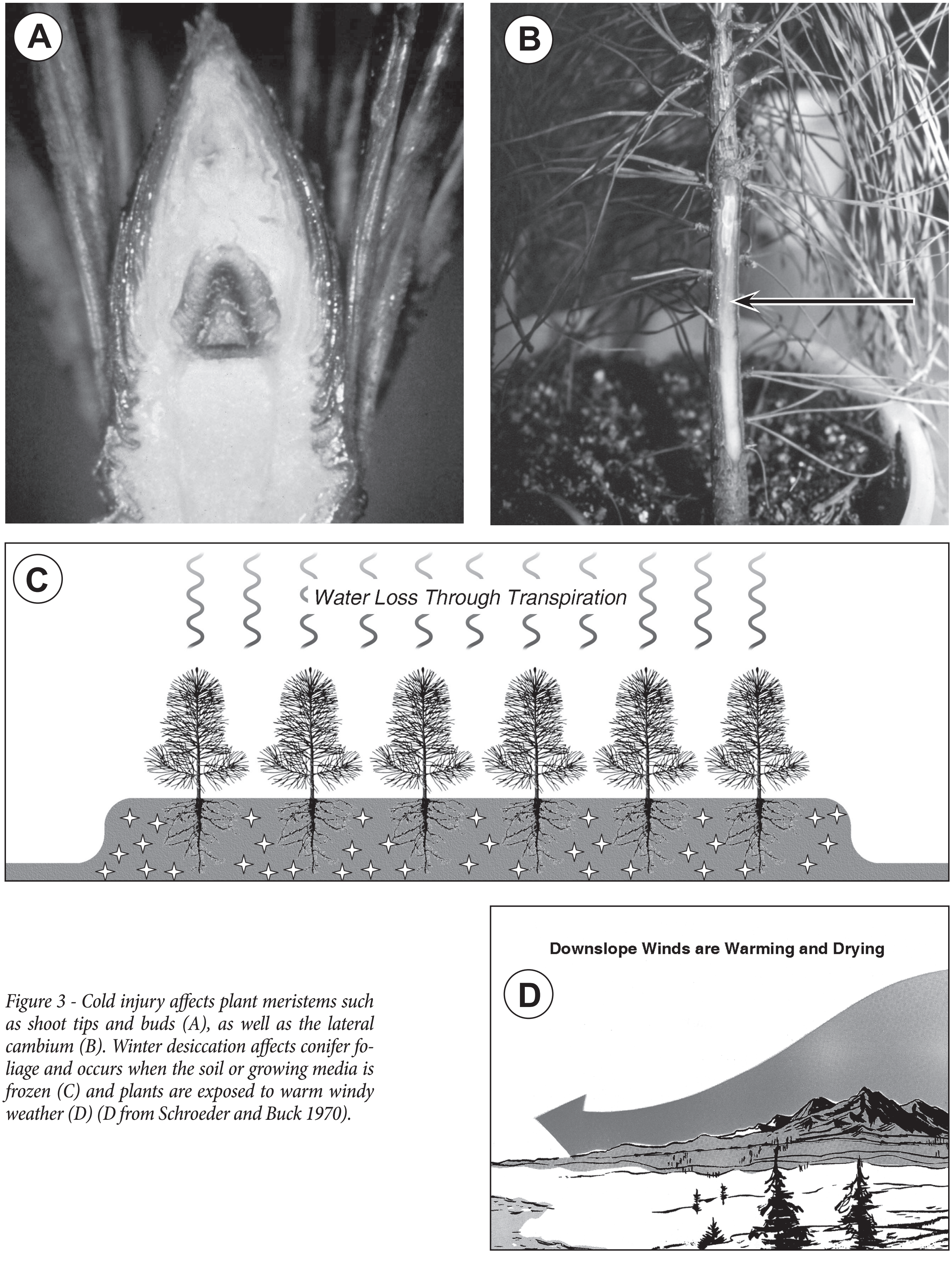

Figure 3 - Cold injury affects plant meristems such as shoot tips and buds (A), as well as the lateral cambium (B). Winter desiccation affects conifer foliage and occurs when the soil or growing media is frozen (C) and plants are exposed to warm windy weather (D) (D from Schroeder and Buck 1970).

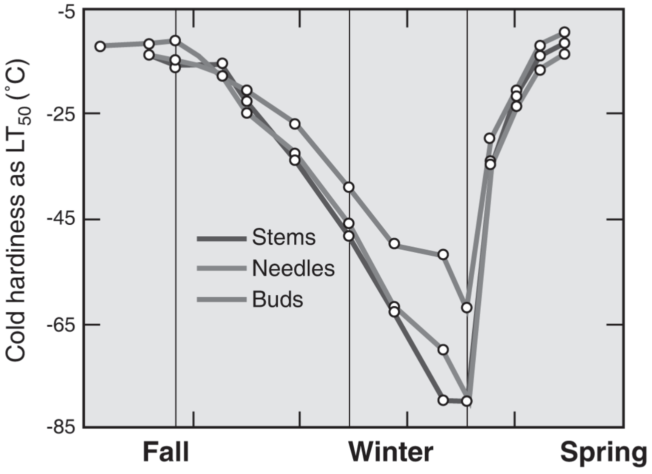

Figure 4 - Woody species from high elevations or high latitudes, such as Englemann spruce, can tolerate extreme cold in midwinter. Plant tissues, however, harden at different rates in the fall, but all deharden very rapidly in the spring (modified from Burr and others 1990).

Cold hardiness of shoots develops in the fall and early winter in response to cooler nights and shortening day length (Table 2). Burr and others (1990) tested cold hardiness of Engelmann spruce seedlings throughout winter and separately examined buds, needles, and lateral cambium. Stems and needles hardened more rapidly and achieved greater midwinter hardiness than buds. All three tissues dehardened very rapidly in late winter (Figure 4).

4. Protecting crops against frost damage with sprinkler irrigation

Growers have used irrigation to protect plant crops during freezing temperatures for about a century, having first been employed by an Ohio farmer in about 1912 (Evans and van der Gulik 2011).

4.1 Reducing cold injury using the heat of fusion

One of the basic concepts of frost protection with irrigation is based on the fact that heat is released as water freezes (Figure 1). The standard recommendation is that overhead irrigation should begin as soon as the temperature approaches the cold hardiness level of the crop, and then the sprinklers must not be turned off until temperatures rise above this threshold (Regan 1988). As crop cold hardiness increases and the starting temperature decreases, growers run the risk of having ice form in the irrigation lines; therefore, be sure that lines are adequately drained after use. As we have already discussed, humidity is as important as actual temperature, so the starting time will depend on both ambient and dew point temperatures (Table 3). If the actual cold hardiness of the crop has been tested, then the starting temperature can be adjusted accordingly. The standard practice is to keep applying water through the overhead sprinklers (thereby releasing heat) until the ambient temperature goes back above the hardiness level for the crop.

In a November 2014 trial at the Webster Forest Nursery (Olympia, WA), i-Buttons® (Maxim Integrated, San

Table 2 – Stages of cold hardening and dehardening for coastal Douglas-fir seedlings (Ritchie and others 2010)

Hardening stage	**Season**	**Environmental cues**	**Temperature tolerance as LT_{50}**
Hardening begins slowly	Late summer to early fall	Shortening photoperiod	28 to 23 °F (–2 to –5 °C)
Hardening increases rapidly	Late fall	Increasing lower temperatures, especially at night	14 to –4 °F (–10 to –20 °C)
Maximum hardiness	Midwinter	Very cold temperatures	5 to –40 °F (–15 to –40 °C)
Dehardening happens quickly	Late winter	Rising temperatures and longer days	Rapidly rising to 28 °F (–2 °C)

Table 3– The proper time to start irrigating for frost protection depends on both the ambient and wet bulb temperatures. Frost protection should be started at higher ambient temperatures when the air is drier (modified from Evans and van der Gulik 2011)

Starting temperature		**Wet-bulb temperature**	
°F	**°C**	**°F**	**°C**
39	3.9	15 to 16	-9.4 to -8.9
38	3.3	17 to19	-8.3 to -7.2
37	2.8	20 to 21	-6.7 to -6.1
36	2.2	22 to 23	-5.6 to -5.0
35	1.6	24 to 25	-4.4 to -3.9
34	1.1	26	-3.3

Jose, CA) were attached to bareroot seedling shoots before sprinkler irrigation was applied and also in an adjacent field with no irrigation. After the frost event was over, temperature data from the i-Buttons was recovered and downloaded (Figure 5). The plots of the two temperatures shows that seedlings protected with irrigation remained within a few degrees of 32 °F (0 °C), compared to the unprotected plants which were exposed to temperatures from 15 to 25 °F (-3.9 to -9.5 °C) for 5 consecutive nights.

4.2 Protection against winter dessication

Sprinkler irrigation is also effective against winter desiccation caused by drying winds blowing over seedlings in cold or frozen soils (Figure 3C-D). In December 2005 at Lewis River Reforestation's nursery (Woodland, WA) a severe cold snap with temperatures down to 12 °F (-11 °C) was ushered in by drying east winds that lose humidity as they move down the western slopes of the Cascade mountains. The nursery manager applied water through sprinklers and left them running until

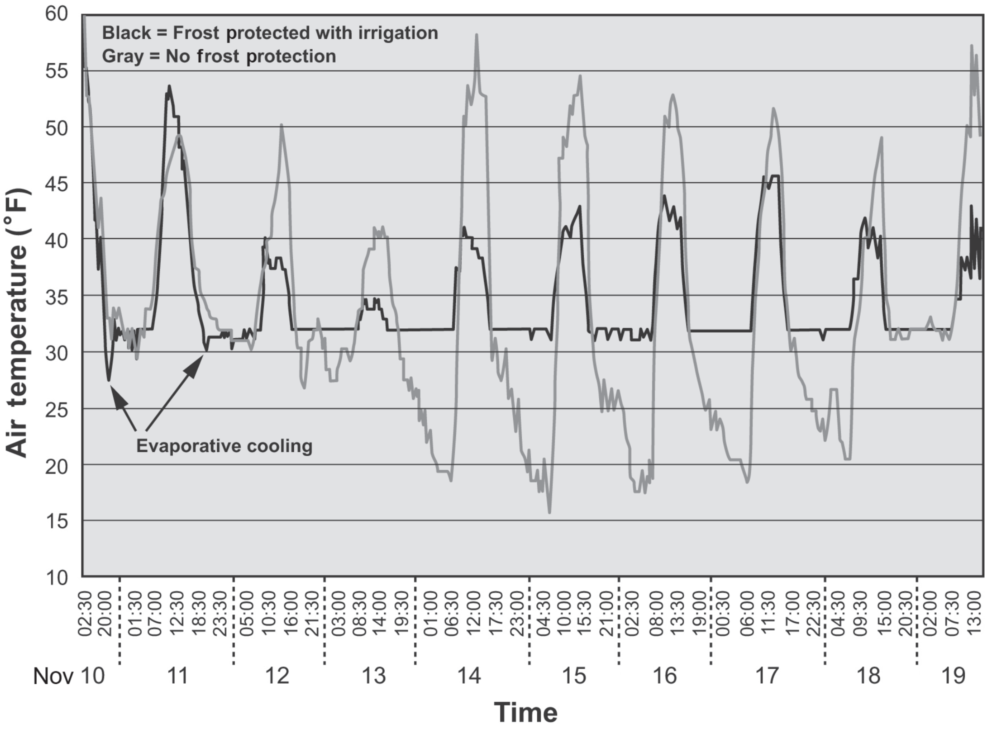

Figure 5 - A comparison of temperature from i-Buttons placed on bareroot seedlings receiving frost protection with sprinkler irrigation compared to control seedlings. Note that, when the frost protection started on November 10 and 11, the temperatures of the irrigated plants were initially lower. This was due to a cool and dry wind that decreased temperatures due to the latent heat of evaporation (see Figure 1) until the water on the plants began to freeze which protected them through the latent heat of fusion.

ice had built up 3 to 4 inches (7.6 to 10.2 cm) thick on his seedlings. Not only did the sprinkler irrigation protect his stock due to the heat of fusion, but the thick ice layer insulated the seedlings and continued protection after the water was turned off (Figure 6). Plant moisture stress (PMS) measurements of iced vs. exposed seedlings indicated reduced stress levels: 3 to 4 bars PMS in seedlings covered by ice, compared with15 bars in the exposed seedlings (Moore 2014).

To test whether a coating of ice has insulating properties, i-Buttons were frozen in varying-sized chunks of ice ranging from an ice cube to a 4 x 5 in (10.2 x 12.7 cm) block. Although the temperatures within the thicker ice were slightly higher, all the tests revealed the relatively poor insulating value of ice. The reason why the Lewis River Reforestation seedlings had some cold protection after the sprinklers was turned off (Figure 6) is probably due to the fact that they were encased in an almost solid block of ice that received some temperature buffering from the underlying soil and thereby also protected the crop from desiccation.

4.3 Operational example: the Webster nursery frost protection system

The frost protection irrigation setup for bareroot seedlings at Webster nursery employs a moveable aluminum pipe/riser setup with plastic rotary (Nelson 2000 K5 plate, 24-degree flow-control) nozzles. When this irrigation system is charged by water pressure of 50 to 60 psi (at the pump), these nozzles throw a radius of 32 to 37 ft (9.8-11.3 m) with a water stream height of 6.3 to 8.7 ft (1.9 to 2.6 m). Riser spacing is 30 ft (9.1 m) down the irrigation pipe with 42 ft (12.8 m) between lines producing an offset pattern. Previously, Webster nursery used Rainbird 7/64" brass impact sprinklers but changing to the plastic rotary sprinklers has resulted in improved frost protection. One of the challenges of frost protection with sprinklers is keeping them from "freezing up". The plastic rotary sprinklers operate with limited maintenance down to temperatures below 10 °F (-12 °C), whereas the brass impact sprinklers typically froze up around 14 to 17 °F (-10 to -8 °C). Under windy conditions, however, rotary sprinklers may not cover as well as impact sprinklers. Nelson offers a "Windfighter" rotator head, but these sprinklers have not been evaluated for frost protection.

5. Summary and recommendations

Using sprinkler irrigation to protect crops from freezing temperature can be effective if done properly. First, make certain that your irrigation system has the proper coverage and that you have enough water reserves to keep applying water as long as you need to. You may want to consider installing sprinklers with plastic

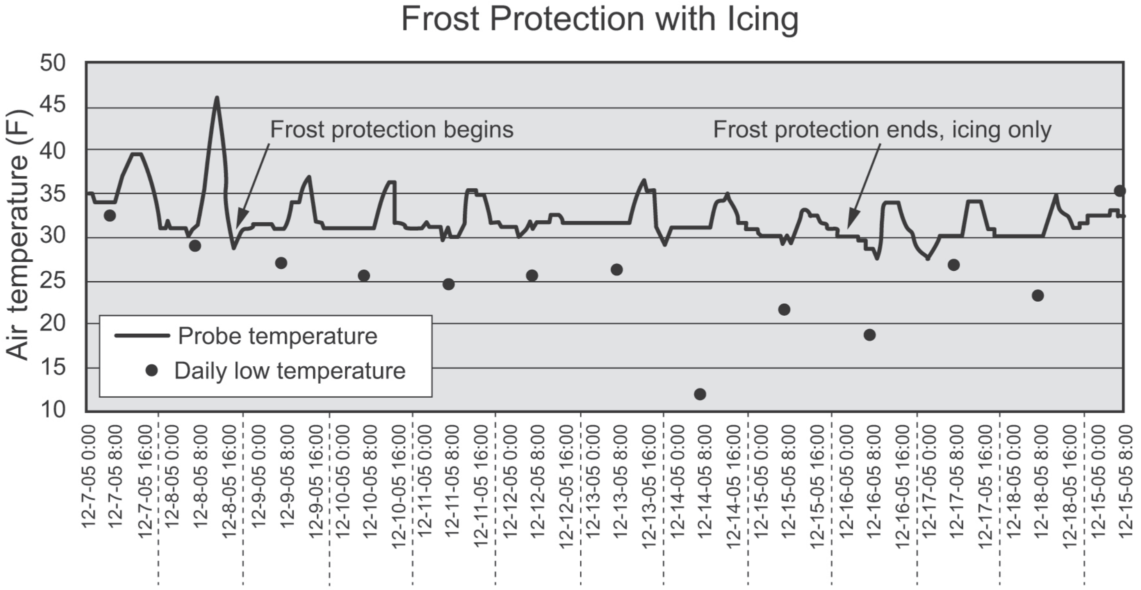

Figure 6 - Temperature probes placed on the terminal shoots of bareroot conifer seedlings and then covered with a thick layer of ice during frost protection show that ice provided some insulation value even after the sprinklers are turned off. More importantly, the ice covering reduced plant moisture stress compared to seedlings that were exposed(modified from Moore 2014).

parts to reduce the chances of them freezing up. Next, determine the frost hardiness of your crops using cold hardiness tests so that you can establish the critical temperature at which to start the sprinkler system. Install a weather station on your nursery or monitor local weather conditions diligently, and pay attention to humidity and wind as well as temperature. Adjust your start frost protection guidelines to account for dew point and wind conditions. Remember that the main frost protection comes from the latent heat released when water freezes so keep applying water until ambient temperature has risen above the danger level. Keep good records so that you can learn from experience and fine-tune your frost protection efforts.

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A quick and easy way to measure container weights for irrigation scheduling

by Thomas D. Landis, R. Kasten Dumroese, and Jeremiah R. Pinto

The following is a expanded discussion on this article from the New Nursery Literature section: #14 - Dumroese RK, Montville ME, Pinto JR. 2015. Using container weights to determine irrigation needs: a simple method. Native Plants Journal 16(1): 67-71.

The practice of weighing containers to determine their water content is one of the oldest cultural practices in forest nurseries. In a survey of container nurseries for the Seedling Nutrition and Irrigation chapter of the Container Tree Nursery Manual (Landis and others 1989), using container weight was the most common technique to determine when to irrigate. The basic concept behind this technique is simple: because water is considerably heavier than other container components, the moisture content of a tray or block of containers can be monitored by weight. A container is heaviest when it has just been irrigated but loses water weight over time through evaporation and transpiration. When the container weight reach reaches some predetermined level (Figure 1), it is time to irrigate.

To minimize variation, it is important to reweigh the same container, which is typically marked with a pin flag stake or is painted a bright color. Forest and native plant nurseries use a wide variety of techniques to weigh their containers:

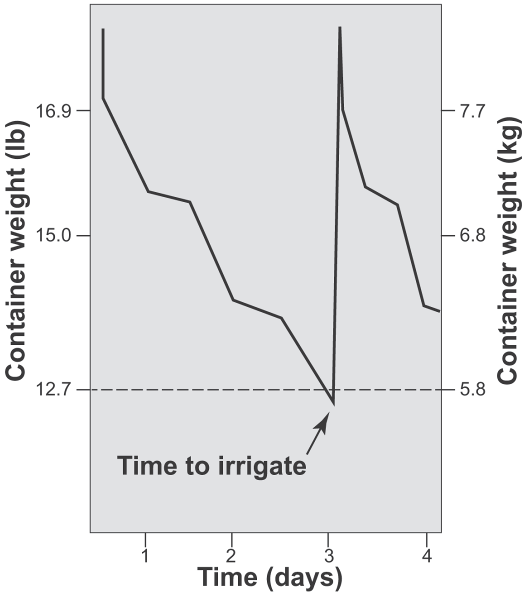

Figure 1 - Container weight is heaviest immediately after irrigation and decreases due to evaporation from the surface of the growing medium and transpiration by the plants. When a predetermined critical weight is reached, 12.7 pounds or 75% of the wet weight in this example, it is time to turn on the irrigation (Landis and others 1989).

1. In small greenhouses, workers can simply carry containers to a stationary balance on a centrally located bench.

2. In larger facilities, a weight scale can be placed on a cart and rolled to various locations.

3. The latest innovation from the PRT nursery in Hubbard, OR is to use an inexpensive, portable, handheld, digital balance to weigh containers. Four 22.5 in long (57 cm) wire hangers that are manufactured for hanging floral baskets are crimped at the end to form a hook. Each wire is stuck through the air vents in the container and twisted to provide support. Then, it is easy to weigh the container with a handheld weighing scale (Figure 2).

The hanging basket wires can be purchased from nursery supply companies at a cost from US$ 0.40 to 2.40 each. The balance used at PRT Oregon is the Chestnut Tools Portable Electronic Scale that can weigh to the nearest one-hundredth unit and sells for about US$ 13 (Lee Valley Tools Ltd; http://www.leevalley.com). This particular unit can be set to either English or metric units, permits conversion between units, and is 99% accurate for loads from 2.2 to 88.9 lbs (1 to 40 kg).

Because the critical (often called target) weight will vary during the growing season, nurseries will need to develop a set of “wet weights” from the Establishment Phase to storage for each container and species combination (Table 1). It may be that with enough data and experience, species with similar water use can be combined into larger, easier-to-manage species groups. Also it is important to know that weight loss

Figure 2 - A Styroblock® container fitted with basket hangers has its weight measured with an inexpensive, portable, handheld, digital balance (Dumroese and others 2015).

can be measured two ways, so when comparing target weights it is essential to know which method is used. In general, nurseries develop target weights based on the change of weight of the entire container without adjusting for the weight of the non-water portion (that is, the container, the dry weight of the medium, topdressing). This method, referred to as the "Manager Technique" or "Grower Method," is fast, simple, and easy. Sometimes target weights are adjusted, however, to only measure the weight of the water; this is most common in science literature when the researchers want to quantify the amount of water used. The biggest difference in these methods, given the same target weight, is that the "Manager Technique" results in a dryer growing medium.

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Table 1 - A container weight scale developed for conifer seedlings in the Pacific Northwest (Landis and others 1989)

Growth phase	**Irrigation weight (% of wet weight)**
Germination	90%
Rapid growth	80%
Hardening	65 to 70%
Packing and storage	80 to 85%

Breaking News: Statistical Proof that Cows Eat Outplanted Seedlings!

by Thomas D. Landis

The following is a expanded discussion on this article from the New Nursery Literature section: # 165 - Renison D, Chartier MP, Menghi M, Marcora PI, Torres RC, Giorgis M, Hensen I, Cingolani AM. 2015. Spatial variation in tree demography associated to domestic herbivores and topography: Insights from a seeding and planting experiment. Forest Ecology and Management 335: 139-146.

I come across all kinds of articles in my literature reviews for FNN, but this one made me chuckle. The research question was why tropical and subtropical high mountains forests are mainly situated within ravines. This condition is called "'the Polylepis problem" (Kessler 2002) because the genus Polylepis is most prevalent in the high mountain forests of South America. The accepted explanation for this phenomenon is that abiotic environmental conditions such as climate, fire, soil moisture, soil depth and other site factors are responsible. To test this hypothesis, the authors seeded and planted seedlings and saplings at three topographic locations: ravines, valleys and ridges and then monitored survival and growth at 5 and 12 years afterwards. Their data was subjected to intensive statistical analysis and their conclusion was that "there could be a strong influence of grazing in restricting high montane forests to sites like ravines where large herbivores are less frequent". A casual glance at one of their bar charts makes statistics unnecessary (Figure 1). The authors also concluded that if the experiments would have been terminated after 5 years, they would have come to a different conclusion - although I have a hard time seeing that from the bar chart.

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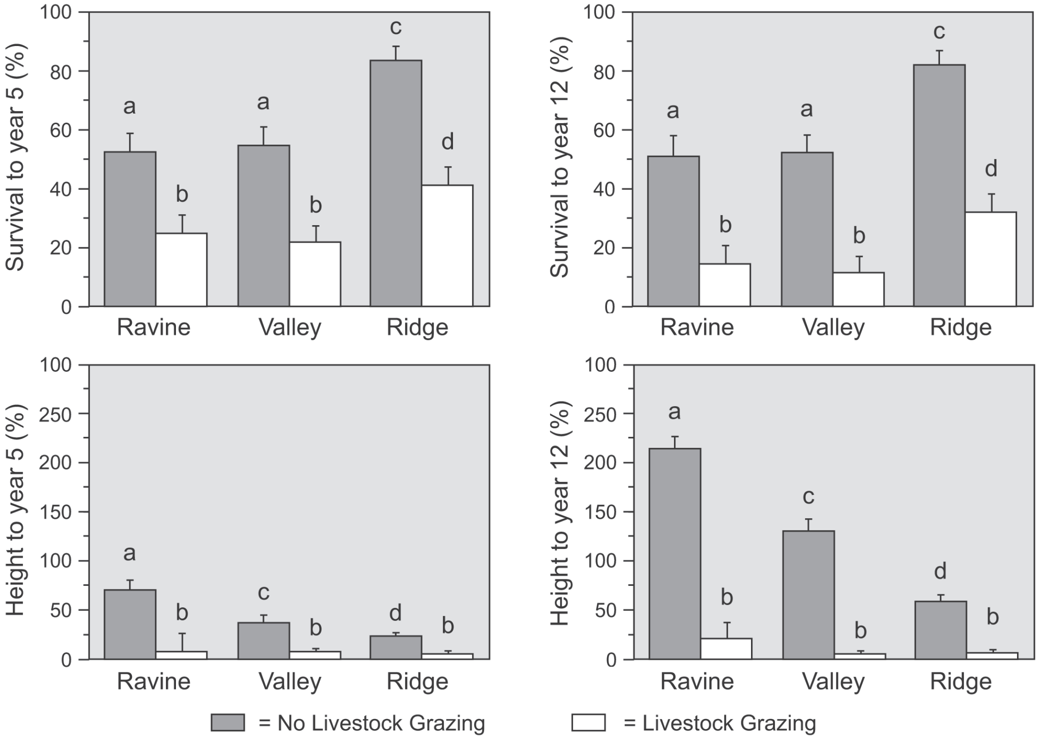

Figure 1 - Survival and height of Polylepis australis *saplings 5 and 12 years after outplanting as a function of topographic position and livestock presence. Different letters above the bars indicate significant differences at the P = 0.05 level. (modified from Renison and others 2015).*

A new *Phytophthora* disease of native plants in California

by Thomas D. Landis

The following is a expanded discussion on this article from the New Nursery Literature section: # 113 - Rooney-Latham S, Blomquist C, Swiecki T, Bernhardt E, Frankel SJ. 2015. First detection in the US: New plant pathogen, *Phytophthora tentaculata*, in native plant nurseries and restoration sites in California. Native Plants Journal 16(1):23-26.

1. Introduction

Phytophthoras (the word means plant destroyers) are water molds—fungal-like organisms that are most closely related to brown algae. The genus *Phytophthora* is large, with over 100 described species, and disease symptoms include blights, cankers, dieback, wilts, root rots, and decline. Some Phytophthoras cause multiple symptoms on a single host, whereas other different symptoms on different hosts (Forest Phythophthoras of the World 2015). Host plants cover the entire gamut of propagated plants from agriculture, horticulture, and forestry. The most famous Phytophthora disease is the potato blight caused by *P. infestans* that devastated Ireland and lead to mass immigation during the mid-1800s. In forest and native plant crops, *P. ramorum* is responsible for the recent sudden oak death of forest trees and shoot and leaf blights in nurseries (Landis 2013a).

Phytophthora tentaculata is a relatively new plant pathogen that causes root and stem rot and was first isolated in 1993 from several floral species in a German nursery. Since then, it has been found on a wide variety of cultivated plants in Spain, the Netherlands, Italy and China. A Plant Epidemiology and Risk Analysis listed *P. tentaculata* as one of the top five Phytophthora species of concern due to potential environmental and economic impact (Frankel and others 2015). Phytophthora diseases are nothing new but what makes this pathogen notable is that it was first discovered in the US on native plants in California. Traditionally, native plants have been considered to be less susceptible to common nursery diseases, but this latest finding raises serious questions about that assumption.

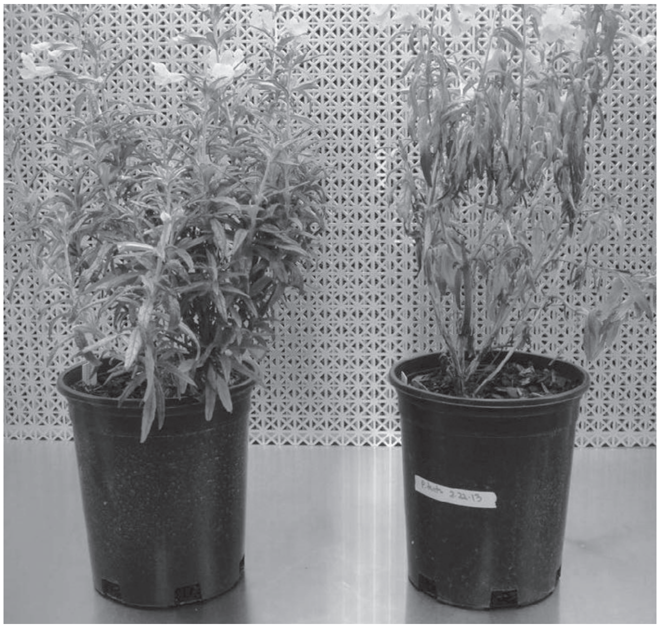

Figure 1 - Sticky monkey flower plants. Left: healthy. Right: Inoculated with Phytophthora tentaculata. *(Photo by Suzanne Rooney-Latham, California Department Department of Food and Agriculture).*

This current infestation started in 2012 when *P. tentaculata* was discovered in a native plant nursery causing a severe root and crown rot in sticky monkey flower (*Diplacus aurantiacus*) (Figure 1). Subsequently, this pathogen has been confirmed on other native California forbs and shrubs including toyon (*Heteromeles arbutifolia*), coffeeberry (*Frangula californica*), and sage (*Salvia* spp.) Disease symptoms include root rot and stem cankers, resulting in wilting and eventual death of infected plants (Rooney-Latham and others 2015).

2. Transmission of *Phytophthora* on nursery stock

One of the major tenets of forest and native plant nurseries is that, because pests flourish in the favorable environmental conditions in the nursery, they will not survive in the harsher conditions on the planting site. Botrytis blight, caused by the fungus *Botrytis cinerea*, is a serious disease in the humid conditions in a container nursery and even thrives in the cold and dark of refrigerated storage (Landis and others 1990a). This fungus often can be found in the senescent foliage in the lower crown

Figure 2 - Phytophthora tentaculata *symptoms on outplanted sticky monkey flower. (Photo by Ted Swiecki, Phytosphere Research).*

of conifer seedlings in nurseries but cannot survive the dry conditions after outplanting. Opportunistic nursery pathogens, like Fusarium root rot (*Fusarium* spp.), can be isolated from the roots of asymptomatic plants but this is not considered as a reason to cull these seedlings (Peterson 2008).

What is worrisome about *P. tentaculata* is that it has been proven to be transmitted to several outplanting sites on infected container nursery stock (Frankel and others 2015). For example the pathogen was isolated from symptomatic sticky monkey flower plants on several outplanting sites in California (Figure 2). Recent investigations into the decline of reforestation plants in nurseries on restoration sites in the Bay Area of California have identified nine other *Phytophthora* species from symptomatic and asymptomatic native plants and nursery soil. Although pathogenicity has not been positively established, these findings strongly suggest that native plant nursery stock can transmit Phytophthora from the nursery to outplanting sites (Rooney-Latham and others 2015).

The destructive potential of nursery transmission of Phytophthora diseases has been shown with *P. ramorum* (Chastagner and others 2012). In the United Kingdom, nursery stock infected with this pathogen was found to be the cause of a devastating forest disease outbreak in a Japanese larch (*Larix kaempferi*) plantation where 3 million trees were killed (Brasier 2012). (For a more detailed discussion of *P. ramorum* in nurseries, see Landis 2013a).

3. Spread of *Phytophthora* diseases within a nursery: Learning from forest nurseries

I have been working with forest container nurseries for more than 30 years and, before this incident, had never seen a Phytophthora disease under modern cultural practices. In fact, in the Disease and Pest Management chapter of the Container Tree Nursery Manual, Phytophthora root rot is only mentioned when compacted growing medium is a problem (Landis and others 1990a). Let's look at some of the cultural practices that prevent Phytophthora from becoming a problem.

1. Seed propagation - Most forest, conservation, and native plants are propagated from seeds whereas many ornamental nurseries use liner stock produced at other nurseries. To my knowledge, Phytophthoras have never been spread on seeds whereas 15 different *Phytophthora* species were isolated from incoming nursery stock in a 3-year study in Maryland (Figure 3). Even more concerning was that most of the plants testing positive were asymptomatic. Certain genera of ornamental plants, including *Rhododendron* spp., *Pieris* spp., *Buxus* spp., and *Ilex* spp. were most commonly infected (Bienapfl and Balci 2014). So, from a disease prevention standpoint, seed propagation has a lot to offer and nurseries should be very careful about bringing liners or other transplants into their facilities.

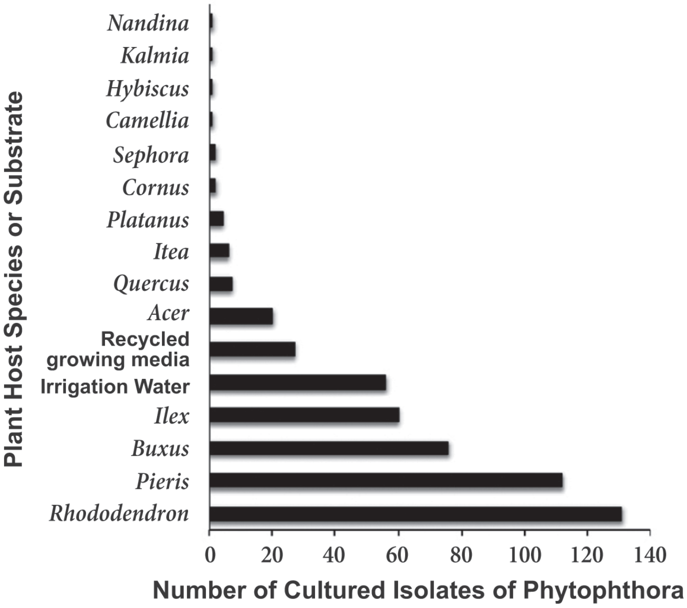

Figure 3 - Fifteen Phytophthora *spp. were isolated from numerous plant species and substrates in Maryland nurseries in 2010, 2011, and 2012 (modified from Bienapfl and Balci 2014).*

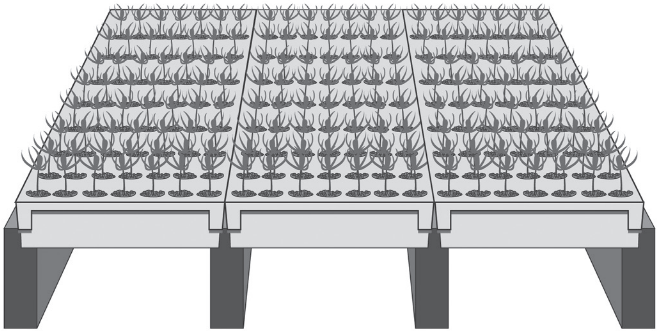

Figure 4 - Because Phytophthora tentaculata*, like all Phytophthoras, is mainly spread through water on nursery floors, the fact that forest nursery crops are grown in small containers on raised benches provides significant disease prevention.*

2. Small volume containers on raised benches - The average stocktype for forest tree seedlings is around 10 cubic inches (164 cc) and these containers are typically located on raised benches where they never come in contact with irrigation runoff (Figure 4). When larger containers are used, they are too heavy for benches and must be placed on the ground. In this situation, the possibility of transmission of waterborne pathogens like Phytophthoras is reduced when containers are placed on a thick layer of gravel to facilitate drainage.

3. Sterile growing media - Most forest nurseries grow their seedlings in completely artificial growing medium composed of some combination of *Sphagnum* peat moss, perlite, and vermiculite. Many of the root diseases common in early container culture including Phytophthoras could be traced to the native soil used in the growing media (Baker 1957). Inorganic growing media components such as vermiculite and perlite are sterilized by high temperatures during processing; however, peat moss and other organic components including composts can be contaminated with pathogens (Landis and others 1990b). Due to the increasingly high cost of peat moss and other traditional components, much research is going into alternative growing media using organic wastes and composts (Landis and Morgan 2009).

In a 3-years study of Maryland nurseries, contaminated growing media was second only to irrigation in cultural practices that spread Phytophthoras (Bienapfl and Balci 2014). To be completely safe, nurseries should consider treating all growing media and components; steam pasteurization has been shown to be effective against a wide range of pathogens in growing media, including *Phytophthora ramorum* (Table 1).

4. Overhead irrigation - Because all Phytophthoras produce motile zoospores, the cultural management of water is the most important disease control. In study of Maryland nurseries, irrigation water was the second only to imported nursery liners as a means of introducing *Phytophthora* spp. (Figure 3). Forest nurseries have traditionally used overhead sprinklers as the main irrigation method (Landis and others 1989). Crops are grown on raised benches are sprinkler irrigated are removed from the major source of *Phytophthora* infestation. All nurseries should have an irrigation management plan organized around best management practices. A systems approach is based on a hazard analysis of critical control points where waterborne pests could gain entry into your nursery (Parke and Grunwald 2012). These comprehensive programs that have been developed for ornamental nurseries can easily be modified for forest, conservation, and native plant facilities. Another approach is based on target pests. Nurseries should learn as much as possible about potential waterborne pests such as *Phytophthora* spp, and determine how, where, and when to test their irrigation water. A complete discussion of which pests can be spread in irrigation water, how to test irrigation water, and options for treating irrigation sources can be found in Landis (2013b).

Table 1 - Steam pasteurization of growing media at 122 °F (50 °C) for 30 minutes has been shown to be effective against soilborne pathogens (modified from Linderman and Davis 2008)

Soilborne pathogens	Recovery of soilborne pathogens (%)					
	Unheated	Temperature treatments for 30 minutes — °F (°C)				
		113 (45)	122 (50)	131 (55)	140 (60)	159 (65)
Cylindrocarpon scoparium	99	56	0	0	0	0
Phytophthora ramorum - Isolate A	77	0	0	0	0	0
Phytophthora ramorum - Isolate B	85	7	0	0	0	0
Pythium irregulare	98	23	0	0	0	0

4. Significance to the nursery industry

Phytophthora diseases have not been a serious concern in forest, conservation, and native plant nurseries, but the fact that the newest (*P. tentaculata*) and most potentially devastating (*P. ramorum*) diseases have been spread in surface water and contaminated growing media should make all nurseries reevaluate their cultural practices. As with all diseases, prevention is the key so managers should conduct a hazard analysis to learn how these pathogens could invade their nurseries. All nurseries want to maintain a good reputation for producing and selling healthy disease-free plants, so the fact that these new Phytophthoras have been shown to be transmitted on nursery stock to outplanting sites should serve as a wake-up call.

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Another Silent Spring?

by Thomas D. Landis

The following is a expanded discussion on this article from the New Nursery Literature section: # 126 - Krischik V, Rogers M, Gupta G, Varshney A. 2015. Soil-applied imidacloprid translocates to ornamental flowers and reduces survival of adult *Coleomegilla maculata*, *Harmonia axyridis*, and *Hippodamia convergens* lady beetles, and larval *Danaus plexippus* and *Vanessa cardui* butterflies. PLoS ONE 10(3): e0119133. doi:10.1371/journal.pone.0119133. 22 p.

#130. Worldwide integrated assessment of the impacts of systemic pesticides on biodiversity and ecosystems. Task Force on Systemic Pesticides. 2015. Environmental Science and Pollution Research 22:1-171.

My first exposure to the book *Silent Spring* was in a high school biology class and, if you have been following environmental issues, the term is back in the news (Bittel 2014; Montbiot 2014). *Silent Spring*, which was written by Rachel Carson in 1962 (Figure 1A), was concerned with the long-term environmental effects of the insecticide DDT. While the correlation between pesticide use and the environment was impossible to scientifically prove, DDT was finally banned by the US Environmental Protection Agency in 1972. One of the most serious environmental effects of DDT was bioaccumulation along food chains; the most famous and controversial was the weakening of egg shells of avian predators such as bald eagles, ospreys, and peregrine falcons. While difficult to prove experimentally, the effect became obvious when eagle populations became to steadily increase immediately after DDT was banned (Figure 1B). The population rebound has been especially obvious to us fishermen as we are seeing many, many more eagles and ospreys than we did when we were kids.

This new silent spring refers to the multiple adverse environmental effects of relatively new systemic insecticides known as neonicotinoids. Imidacloprid, the first commercially available "neonic" insecticide, has only been in use since the 1990s, but neonicotinoids are now the most widely used insecticides in the world. As they are water soluble, neonicotinoids are readily absorbed by plants via either their roots or

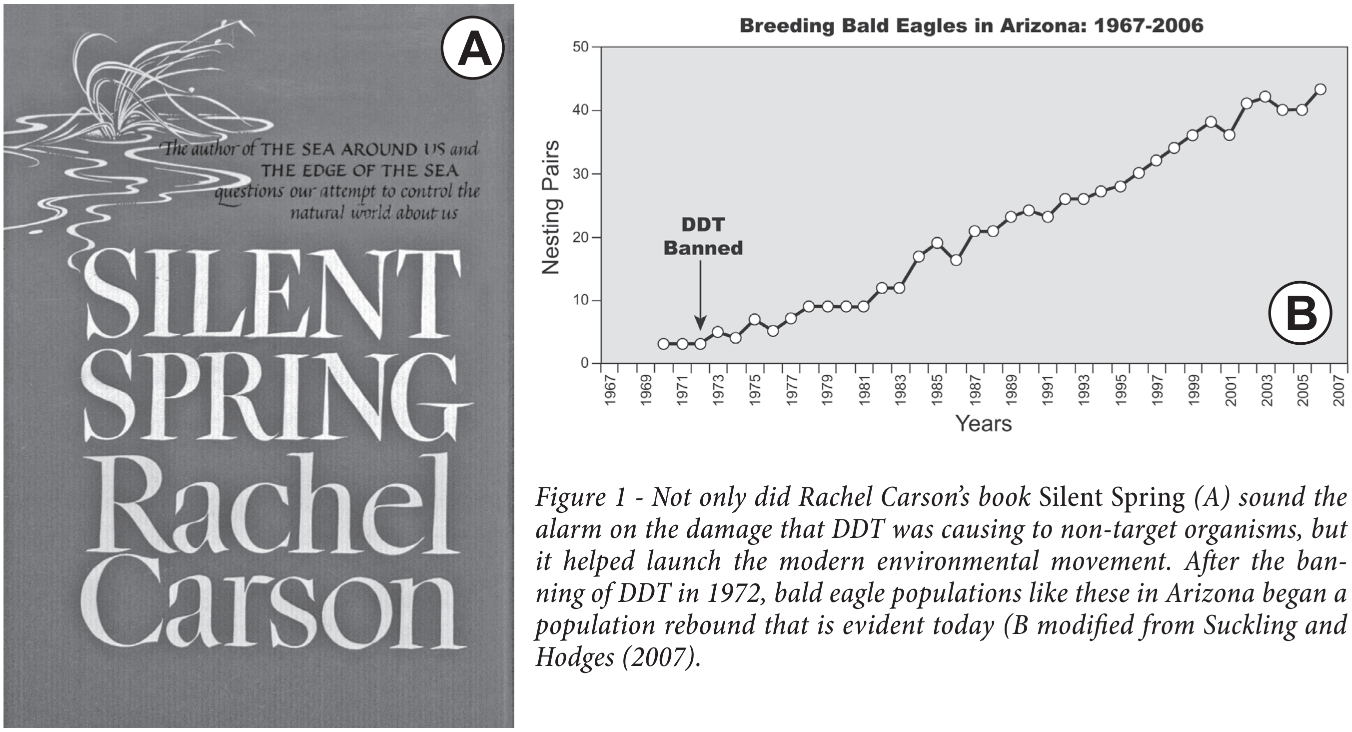

Figure 1 - Not only did Rachel Carson's book Silent Spring *(A) sound the alarm on the damage that DDT was causing to non-target organisms, but it helped launch the modern environmental movement. After the banning of DDT in 1972, bald eagle populations like these in Arizona began a population rebound that is evident today (B modified from Suckling and Hodges (2007).*

leaves and then readily transported throughout plant tissues. One major benefit of these pesticides is that they are effective at very low concentrations; 5 and 10 ppb (parts per billion) can provide protection against insect pests. So, in major agricultural crops, neonicotinoids are applied to seeds and then spread throughout the plant. Thus, they are even effective against boring and root-feedings insects that are impossible to reach with traditional insecticides. Although seed applications are most common, neonicotinoids have proven effective in a variety of other applications: soil drenches, injected into irrigation water, and even as sprays for homeowner use on flowers and vegetables (Goulson 2013).

Neonicotinoids were initially considered much safer than other pesticides due to their low toxicity to vertebrates. As with DDT, however, the evidence that neonicotinoids have been harming non-target organisms has been slowly accumulating primarily due to anecdotal observations that are hard to prove scientifically. A strong correlation has been noted between the use of neonicotinoid concentrations and the decline of bird populations in Europe (Hallman and others 2014). Being systemic, small concentrations of neonicotinoids are found in both pollen and nectar of treated crops that could have negative effects on pollinators, especially honey bees. The main concern is not direct toxicity but rather sublethal impacts that affect bee behavior. Compelling evidence has linked these insecticides to colony collapse disorder which drastically affected beekeepers around the world (Lu and others 2014). Neonicotinoids were also implicated in the low reproductive success of bumblebees (Laycock and others 2012). Most alarming, however, was the death of an estimated 50,000 bumblebees in Oregon from the non-label application of a neonicotinoid insecticide known as Safari (Black and Vaughan 2013).

What brings this issue home to nursery growers is the feature article showing that higher rates of soil-applied imidacloprid used in nurseries and greenhouses resulted in floral concentrations that were 793 to 1,368 times higher than that measured in seed treatments. A research trial showed that these higher insecticide levels caused significant mortality of 3 species of lady beetle and the caterpillars of two species of butterflies, including monarchs (Figure 2). While the caterpillar mortality is alarming, the more insidious threat is to beneficial insects which are critical to many integrated pest programs (Krischik and others 2015).

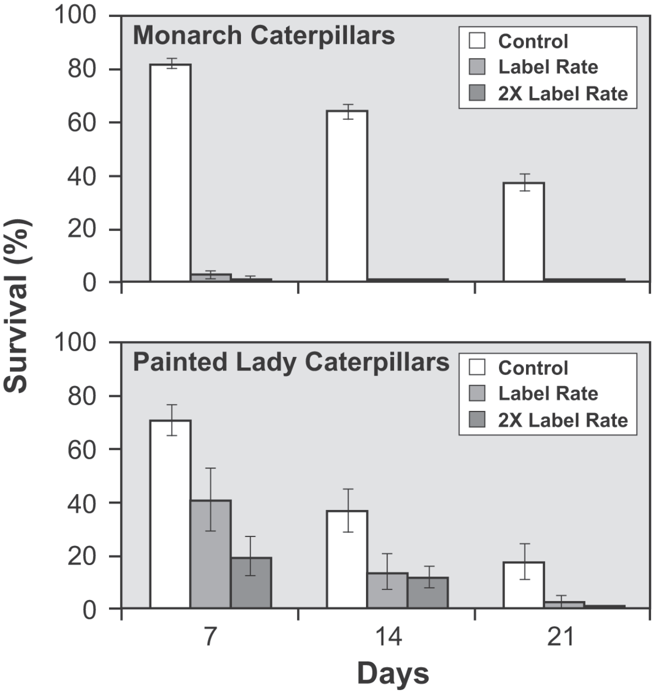

Figure 2 - Soil applications of a neonicotinoid insecticide (imidacloprid) at label rate (1X), or twice label rate (2X) significantly reduced the survival of the larvae (caterpillars) of two common butterflies (modified from Krischik and others 2015).

A recent review by a worldwide panel of scientists found that a compelling body of evidence has accumulated that clearly demonstrates that these persistent, water-soluble chemicals are having widespread, chronic impacts upon global biodiversity and ecosystem services such as pollination. They urged an immediate reduction in the use of neonicotinoids and reversion to an Integrated Pest Management approach (van der Sluijs and others 2015). Countries of the European Union and Canada are vigorously attacking the problem, and it remains to be seen whether the US will follow suit.

"All the science is not done, but everything that I have before me. . . suggests to me that this is the biggest threat to the structure and ecological integrity of the ecosystem that I have ever encountered in my life, bigger than DDT" — Miller (2014)

"The systemic insecticides, neonicotinoids and fipronil, represent a new chapter in the apparent shortcomings of the regulatory pesticide review and approval process that do not fully consider the risks posed by large-scale applications of broad-spectrum insecticides to ecosystem functioning and services. **Our inability to learn from past mistakes is remarkable"** — van Lexmond and others (2015)

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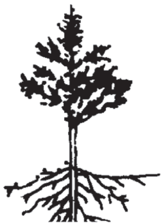
The Container Tree Nursery Manual series is now available in Spanish.

The funding for the translation and printing was provided by the Comision Nacional Forestal, Secretaria de Medio Ambiente y Recursos Naturales, and I would like to acknowledge the dedication and persistence of Rafael Alvarez Reyes in seeing this project through. The translations were done by: Dante A. Rodriguez Trejo, J. Ricardo Sanchez Velazquez, Rebeca Aldana Barajas, and Mauricio Mendoza Briseno. Working through his nonprofit organization Reverdece, Pedro Hernandez Provenzal was invaluable in facilitating this project and deserves a special thank you.

Pedro has also agreed to handle requests so you can contact him at the following E-mail address: mexicopedro@hotmail.com

Tropical Nursery Manual also still available—see page 46.

Bareroot Production



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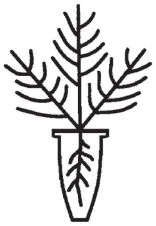

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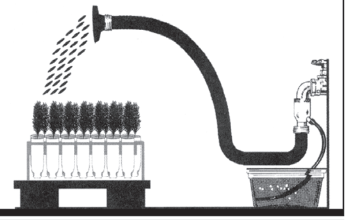

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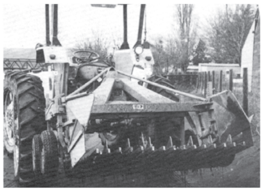

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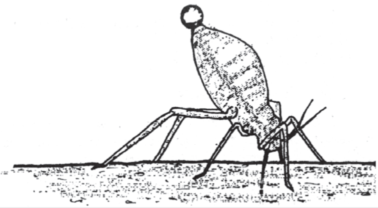

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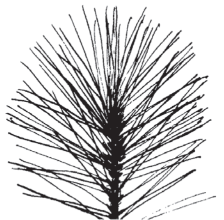

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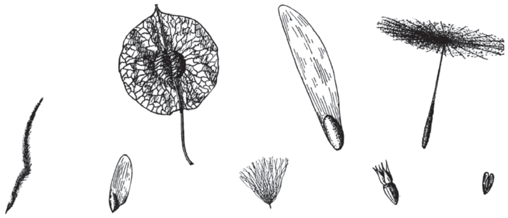

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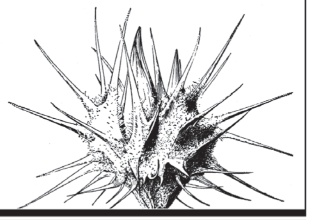

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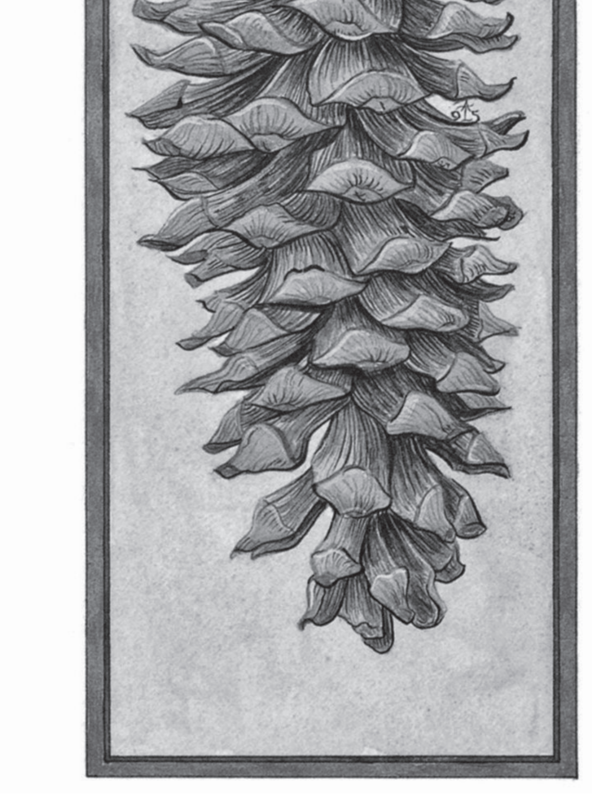

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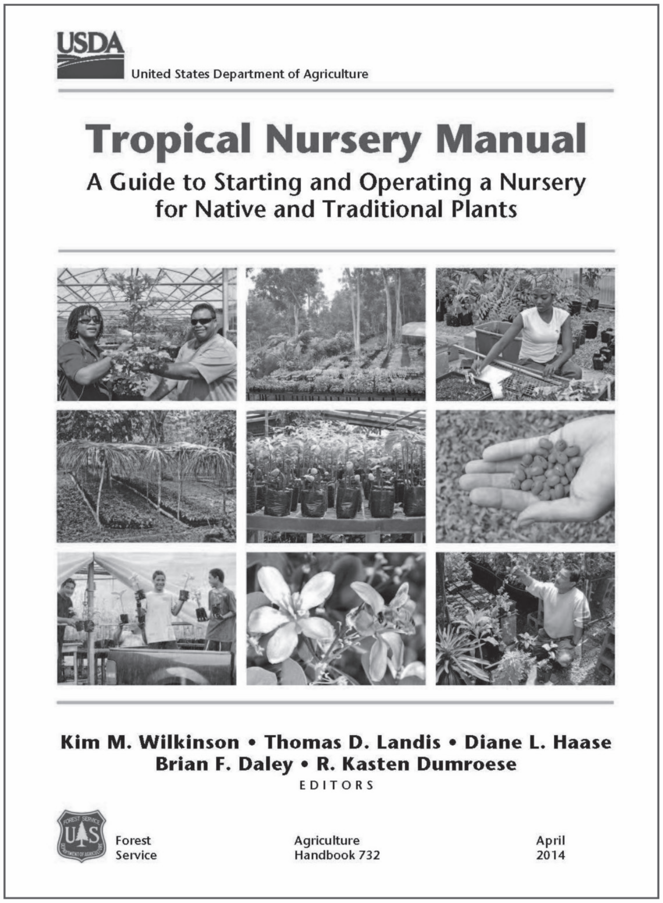

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