The Container Tree Nursery Manual

Volume Seven

Chapter 4
Plant Storage

Contents

7.4.1 Introduction

Unlike some agricultural commodities that can be stored for extended periods without a decrease in quality, container nursery crops are living and have a very limited "shelf life." Therefore, well-designed storage facilities are needed at all native plant nurseries.

Plant storage was not a serious consideration back in the days when nurseries were established close to the outplanting project. This allowed plants to be dug up in the nursery one day and outplanted the next. Transportation was slow and plant handling and packaging were rather simple (fig. 7.4.1). Reflecting on those days and knowing what we now do about plant physiology, it is amazing how well many of those early plantations performed.

It is important to realize that plant storage is an operational necessity, not a physiological requirement (Landis 2000), because of the following four reasons.

7.4.1.1 Distance between nursery and outplanting site

Today, most native plant nurseries are located at great distances, often hundreds or even thousands of miles, from the outplanting sites of their customers. This is particularly true of container nurseries because, as long as the proper seed source is used, high-quality plants can be grown in greenhouses in ideal growing environments located far away. The farther the distance from the nursery to the outplanting site, however, the greater the need for storage.

7.4.1.2. Differences between the lifting window at the nursery and outplanting windows

As mentioned in the previous section, container nurseries are often located in climates different from those of their customers. In mountainous areas, this is especially true, because nurseries are typically located in valleys at low elevation that have much different climates than outplanting sites at higher elevations. Differences between lifting and outplanting windows will also depend on the season of outplanting. If customers desire summer or fall outplanting, then short-term storage is all that is necessary. Often, however, the best conditions for outplanting occur the following spring, so it is necessary to protect plants throughout winter.

Figure 7.4.1—*Early forest nurseries did not need storage facilities because seedlings were shipped and outplanted within days. Note that the workers are sitting atop the bales of nursery stock.*

7.4.1.3 Facilitating harvesting and shipping

The large numbers of plants being produced at today's nurseries means that it is physically impossible to lift, grade, process, and ship stock in a short time. Therefore, one primary benefit of storage facilities is that they help to spread out the scheduling and processing during harvesting and shipping.

7.4.1.4 Refrigerated storage can be a cultural tool

Many growers do not appreciate the fact that refrigerated storage can be used to manipulate plant physiology of a variety of plants. Cold storage temperatures can partially satisfy the chilling requirement of dormant stock, and refrigerated storage has even been shown to improve plant quality (Ritchie 1989). Class 2 Douglas-fir (*Pseudotsuga menziesii*) seedlings were found to gradually increase in quality to Class 1 while in storage (fig. 7.4.2). On the other hand, plants with atypical dormancy patterns may not benefit from refrigerated storage. Cold storing water oak (*Quercus nigra*) seedlings did not appear to prolong dormancy, increase stress resistance, or increase outplanting performance (Goodman and others 2009). A complete discussion of dormancy and other aspects of plant quality can be found in Chapter 7.2.

7.4.2 Short-Term Storage for Summer or Fall Outplanting —"Hot-Planting"

Container stock that will be outplanted during summer or fall is not completely dormant or very stress resistant so it requires special consideration. The term "hot-planting" is used to describe this type of operation, because no extended period of refrigerated storage is employed. Plants are typically held in the hardening structure, which is usually a shadehouse or open compound, until they are shipped (fig. 7.3.3A). In the Southern United States, hot-planted container stock is stored in coolers or refrigerated vans at 4 to 21 °C (40 to 70 °F) for no more than a week (Dumroese and Barnett 2004).

Recent research has shown that nondormant nursery stock can perform well when hot-planted (Helenius and others 2005). Both actively growing and cold-stored Norway spruce (*Picea abies*) container stock were planted and then subjected to increasing periods of moisture stress. The nondormant seedlings that were hot-planted had significantly more new roots growing out of the container plugs ("root egress") than the cold-stored stock for the first 2 weeks after outplanting (fig. 7.4.3B).

Hot-planting can be successful in the summer and fall when conditions are ideal on the outplanting site. This system offers a lot of flexibility because plants can be held at the nursery and shipped as they are needed. On the outplanting site, nursery stock should be stored upright and kept in the shade. Using white boxes helps to reflect light and keep in-box temperatures lower (Kiiskila 1999). Hot-planting requires close coordination between the nursery and the customer; therefore, projects are usually close to the nursery and relatively small.

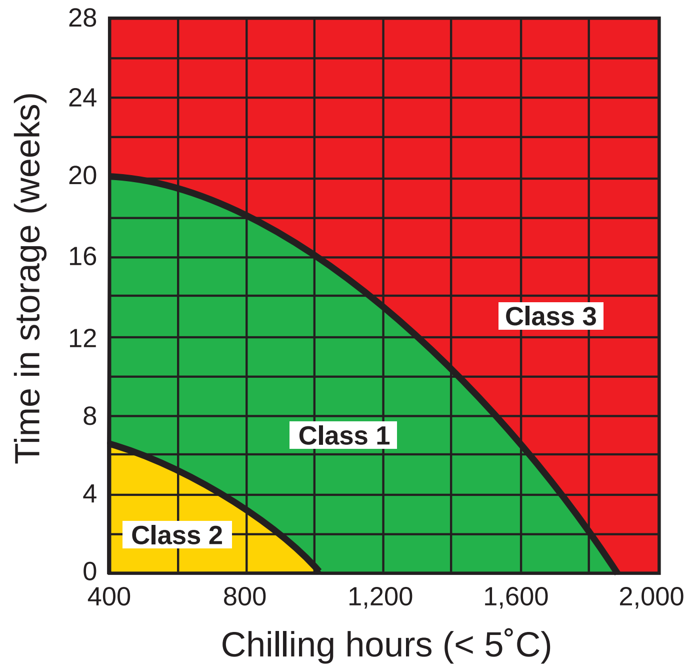
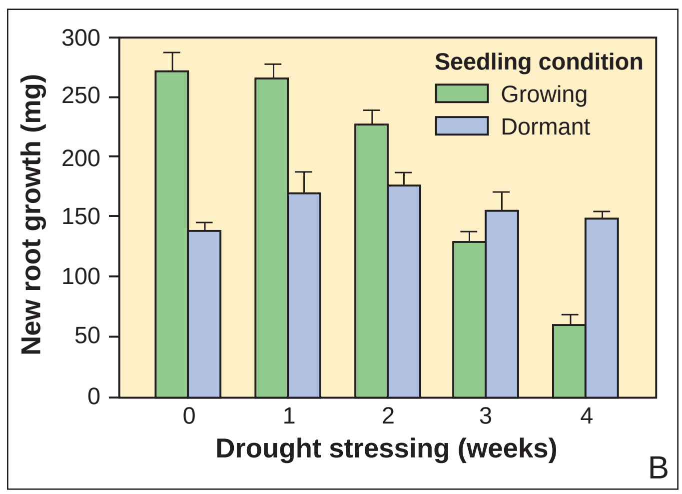


Figure 7.4.2—*Refrigerated storage can partially fulfill the chilling requirement of dormant nursery stock, and, in the case of Douglas-fir, has been shown to actually increase seedling quality—a move from the yellow to the green zone (modified from Ritchie 1989).*

A

Figure 7.4.3—*Because they are not dormant or stress-resistant, hot-planted stock is held in the hardening area until shipped (A). In research trials, hot-planted spruce seedlings had better new root growth in the first 2 weeks after outplanting compared with stock that had been cold-stored (B, modified from Helenius and others 2005).*



7.4.3 Overwinter Storage

The importance of properly overwintering stock is often overlooked by novice nursery managers because they are primarily focused on growing the crop. Plants are frequently damaged and some crops have been completely lost as a result of poorly designed or managed overwinter storage (fig. 7.4.4A). Although dead plants are dramatic, what is more insidious is sublethal injury, in which roots are seriously damaged (fig. 7.4.4B). Unfortunately, sublethally damaged plants often do not develop injury symptoms under ideal nursery conditions; instead, the injury is reflected in poor survival and growth on the outplanting site. The risk for overwinter injury is very much dependent on the physiological condition of the plants at the time of storage (discussed in Chapter 7.3) and on proper storage techniques and conditions.

7.4.3.1 Designing and locating a storage facility

The time to first think about plant storage facilities is during the nursery development phase, but, unfortunately this is often not done. The design and location of a nursery storage system depends on the following four factors.

The general climate at the nursery. Most people think that overwinter storage would be more difficult the farther north or higher in elevation one goes, but that is not always the case. Nurseries in the Midwest or southern Great Plains regions of the United States are often the most challenging because of extreme weather fluctuations during winter (Davis 1994). An extreme case is the eastern slope of the Cascade Mountains or Rocky Mountains, where temperatures can vary by as much as 22 °C (40 °F) or more within a 24-hour period, and high, drying winds are common during winter and early spring. At one nursery in Alberta, a 5-year study on plant quality in outdoor compounds documented recurring damage and mortality because of late frosts and unusually warm periods during late winter (Dymock 1988). It can also be difficult to store container stock in areas such as the Southwestern United States, where winter is characterized by many clear, sunny days. Therefore, each nursery must develop a storage system appropriate for the local climate.

Characteristics of nursery stock. Some plants are easier to store than others, so storage systems must match the plant species being grown. Species that tend to overwinter well are those that achieve deep dormancy and can withstand low or fluctuating temperatures. Deciduous plants have a definite advantage because their lack of foliage when dormant reduces the possibility of winter desiccation. Evergreen species are prone to both cold injury and moisture loss, and broadleaf evergreen species are particularly troublesome. Species and ecotypes from coastal areas that are never exposed to freezing tend to be less hardy than those from inland areas. This makes it particularly challenging for nurseries that grow seedlots from a wide range of elevations. For example, coastal sources of Douglas-fir tend to grow late in the season and are much less hardy than seedlots from higher elevations in the mountains. In tropical or semitropical climates, plants never undergo true dormancy and can be outplanted almost any time of the year.

All temperate and arctic plants go through an annual cycle of growth and dormancy (see Chapter 7.2). In nurseries, plants are cultured through an accelerated period of growth that must be terminated before they

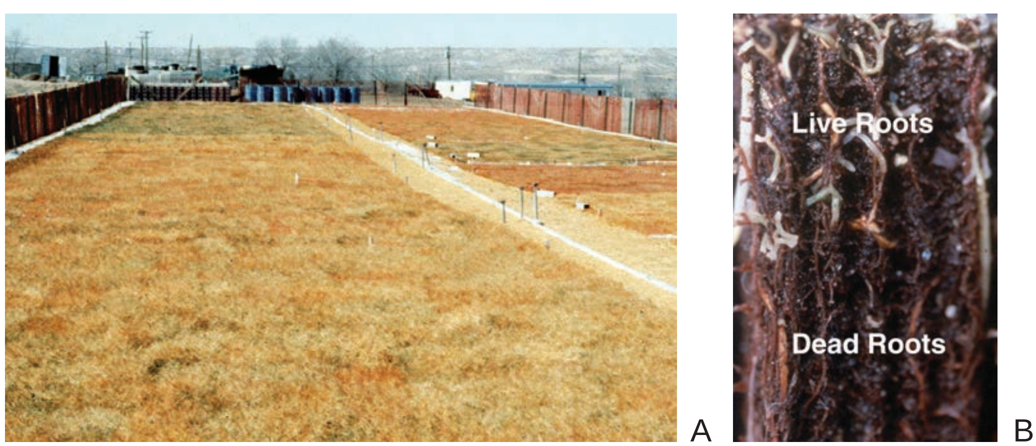


Figure 7.4.4—*Entire crops of nonhardy plants have been lost to sudden freezing temperatures when improperly stored (A). Sublethal injuries, such as cold injury to roots (B), are of greater concern because foliar symptoms are slow to develop under nonstressful nursery conditions.*

can be outplanted; this is the hardening period. In Volume 6, we discussed ways in which growers can harden their stock and prepare them for storage. Plants that are fully dormant and cold hardy are in the ideal physiological state for overwinter storage. Dormant, hardy plants can be thought of as being in a state of "suspended animation." They are still respiring and some cell division occurs in the roots and stems (see Figure 7.2.35 in Chapter 7.2); evergreen species can even photosynthesize during favorable periods during winter. The challenge to nursery managers is to design and manage a storage system to keep their stored plants dormant while protecting them from stress.

Distance to the outplanting sites. Nurseries located close to the outplanting sites may be able to hot-plant their stock with little or no storage. As the distance increases, however, some type of storage facility is needed. Nurseries that are in a climate different from their customers' climate need the most sophisticated and expensive storage systems. Because they grow stock from many different elevations with differing outplanting windows, Weyerhaeuser nurseries in Oregon and Washington use freezer storage where plants can be held for as long as 6 months (Hee 1987). The Forest Service J.H. Stone Nursery in southern Oregon has grown commercial conifers for clients across the Northwestern United States, but those from high elevations in Idaho require special handling and, therefore, incur more costs than those for local customers. On the other hand, clients in the coastal forests of Oregon can outplant throughout the winter, and so receive their plants with minimal storage.

Number and size of plants to be stored. As already mentioned, larger nurseries face a greater challenge in processing their stock, and storage systems help provide a buffer. In addition, larger container stock requires special storage considerations. For example, it is relatively easy to store a large number of 66 cm^3 (4 in^3) plants under refrigeration, but the same number of 328 cm^3 (20 in^3) plants would require four times as much space. Very large stock, such as 20-L (5-gal) containers, requires too much refrigerated storage space and so must be stored by other means.

7.4.4 Nonrefrigerated Storage Systems

Individual native plant species have distinct requirements for overwinter storage. Because of this and unique local climates, four different types of overwinter storage are commonly used in forest and conservation nurseries. Most nurseries typically use several types of storage. Three of the types of overwinter storage avoid refrigeration and are discussed in this section; refrigeration, the fourth type of storage, is discussed in Section 7.4.5.

7.4.4.1 Open storage

Open storage is the least expensive but most risky overwintering option in areas with freezing temperatures. This is especially true for small-volume container stock that has less thermal mass of the growing media to protect sensitive roots from freezing. In addition to having more thermal mass, larger containers also contain more moisture that protects against overwinter drying. Thus, the smaller the container, the higher the risk of injury.

The best locations in a nursery for open storage have some protection from the wind and are where water and cold air will drain away. Gravel and/or drainage tile should be used to promote free drainage of rain or snow melt in the spring. Packing containers together tightly on the ground and insulating their perimeter with straw bales or a berm of sawdust makes use of heat stored in the ground to protect the roots of the stored plants (fig. 7.4.5A). A research trial in Sweden showed the importance of grouping container plants and placing them directly on the ground (Lindstrom 1986). Temperatures in the peripheral containers were consistently lower than those in the interior by as much as 3 °C (5.4 °F) and fluctuated greatly. At the end of the overwinter period, plants were placed in a growth chamber to observe their performance; those stored directly on the ground had much more shoot and root growth than those stored on pallets that were 10 cm (4 in) above the ground (fig. 7.4.5B). To keep plant roots from growing into the ground, nurseries can underlay all open-stored stock with heavy poly sheeting or a copper-treated fabric that chemically prunes the roots (fig. 7.4.5C).

Open storage is most successful in forested northern climates, where adjacent trees create both shade and a windbreak, and continuous snow cover can be expected. If tree cover is not available, plants can be stored in narrow east-to-west oriented bays between vertical snowfences (fig. 7.4.5D). Snow is an ideal natural insulation for overwintering container plants, but complete and continuous snow cover is not always reliable. Some northern nurseries have had success with generating snow cover with snowmaking equipment (Davis 1994) (fig. 7.4.5E).

7.4.4.2 Structureless storage systems

Next to open storage, structureless storage systems are the simplest and least expensive ways to overwinter container stock. The term “structureless” means that plants are enclosed in a protective covering that lacks substantial mechanical support. Many different coverings have been used but the basic principle is the same—to provide a protective, insulating layer over the stored plants. Clear plastic should never be used because it transmits sunlight so that temperatures within the storage area can reach damaging levels or cause stock to lose dormancy. All plastic coverings will be eventually photodegraded by direct sunlight, so they should be stored in a dry, dark location when not in use (Green and Fuchigami 1985). Any structureless storage system is effective only if applied after plants have developed sufficient hardiness and, most important, removed before plants lose dormancy in the spring.

White plastic sheeting. Single layer films, such as a 4-mil white copolymer plastic sheeting, are the most common coverings in structureless systems. White is preferred because it reflects sunlight and keeps temperatures from buildingup under the covering. Some growers group blocks of containers together with the roots to the inside and then cover them with white plastic (fig. 7.4.6). This is less effective, however, than grouping the containers together on the ground to take advantage of the heat stored in the soil (fig. 7.4.5A).

White Styrofoam™ sheets and panels. Microfoam® is a breathable Styrofoam-like material that is lightweight, reusable, and easily removed and stored. It is available in rolls or sheets of various widths, lengths, and thicknesses (fig. 7.4.7A). Sheets can be placed directly over plants (fig. 7.4.7B) or supported by wood stakes or wiring. Because Microfoam® is so lightweight, it needs to be secured well so that it does not rip or blow away during windstorms. Typically, the foam sheets are secured around the edges

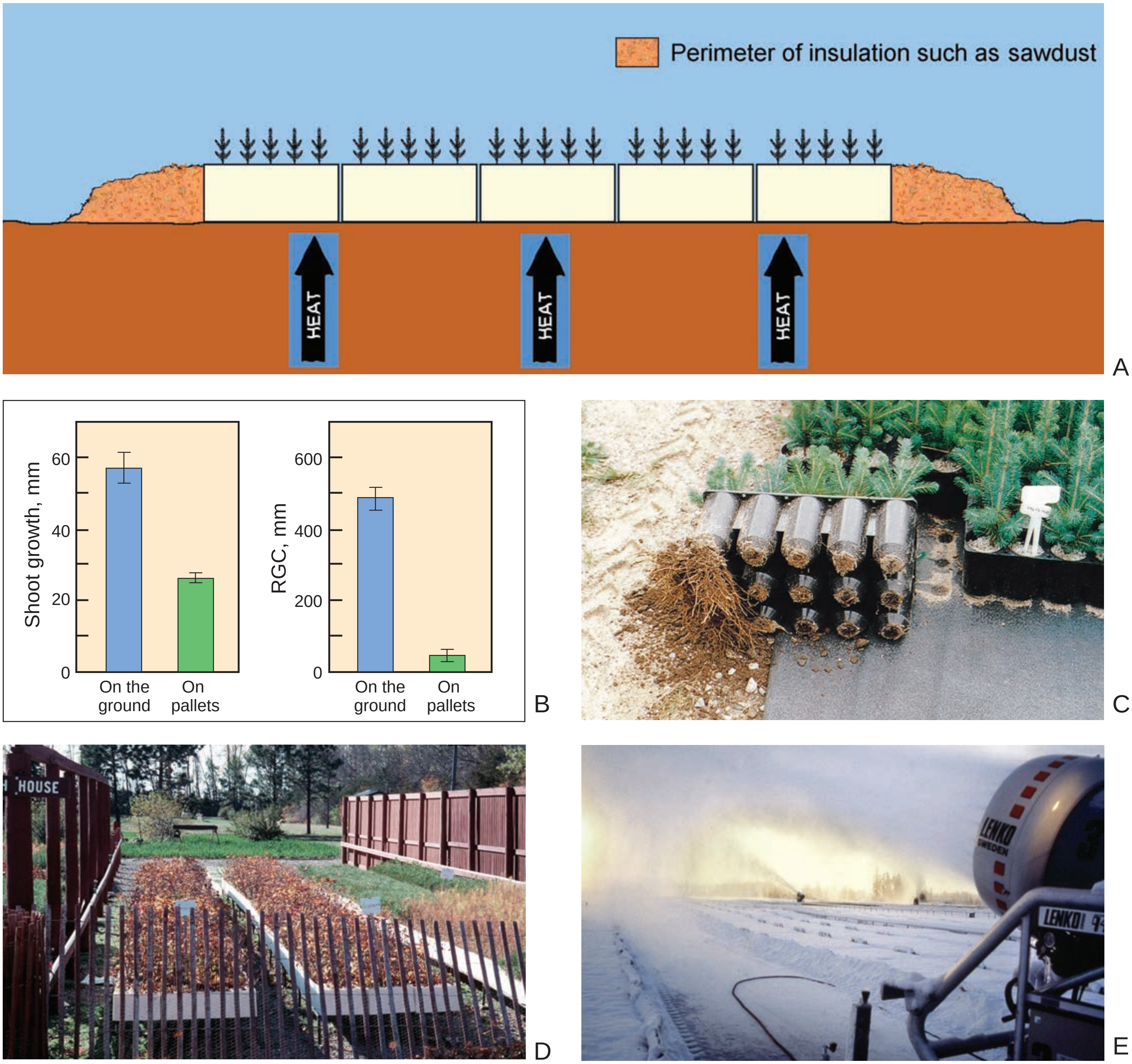


Figure 7.4.5—*Open storage can be effective when plants are blocked on the ground and surrounded by insulation (A). Both shoot growth and root growth potential of seedlings overwintered on the ground were much greater than those stored on pallets (B). Copper-treated fabrics, like Tex-R® (C), are ideal for ground storage because they chemically prevent plant roots from growing into the ground. Open-stored plants should be protected from direct sun and wind by natural or artificial snowfences (D). Snow is an excellent insulator and northern nurseries have augmented natural snowfall with snowmaking equipment (E) (B, modified from Lindstrom 1986; C, courtesy of Stuewe & Sons, Inc.; E, courtesy of Maurice Dionne).*

Figure 7.4.6—*White plastic reflects the warming rays of the sun but, by itself, has no insulation value; so it is better to leave the containers on the ground.*

with concrete blocks, wooden planks, or even a berm of sand. In a comprehensive trial in Ontario, Styrofoam SM™ blankets protected conifer seedlings from temperatures below –30 °C (–22 °F) with a significant cost savings compared to refrigerated storage (fig. 7.4.7C). The authors recommended removing insulating covers during warmer weather to allow condensation to escape and prevent overheating of stock nearest the ground. Subsequent outplanting trials produced almost identical results in survival and growth (fig. 7.4.7D) (Whaley and Buse 1994). In another test, however, one layer of Microfoam®, in the absence of reliable snow, did not provide enough protection in the harsh climates of northern Minnesota and North Dakota (Mathers 2004). As with all new techniques, nurseries considering using insulating covers should install small trials before attempting operational use.

Plastic Bubble-Wrap™ sheeting. This material has better insulation than regular plastic sheeting and is reported to be cheaper and more durable than Microfoam® sheets (Barnes 1990). Because it is clear, however, heat buildup would still be a problem on sunny days.

Frost fabrics. Woven and nonwoven landscape fabrics have been used for structureless storage. White frost fabrics retard solar heating while permitting infiltration of rain or snow melt; they allow stored plants to "breathe." Horticultural suppliers offer frost fabrics in a range of weights and thicknesses, giving 2 to 4.5 °C (4 to 8 °F) of thermal insulation. Arbor Pro® is a feltlike material that has been used successfully for conifer storage in eastern Canada (White 2004).

Plastic film with layer of insulating material. In harsh, northern climates without reliable snow cover, some nurseries cover their container stock with a "sandwich" of straw or other insulating material between two layers of clear plastic sheeting. Because the clear plastic and straw absorb solar heat on clear, frigid days, and the straw provides insulation during the night, this layering provides more overwinter protection than other structureless systems (Mathers 2003). Although layered coverings provide good insulation, they cannot be removed or vented during periods of sunny warm winter weather (Iles and others 1993).

For nurseries considering overwintering with coverings or in poly tunnels, Green and Fuchigami (1985) provide operational costs for various systems.

7.4.4.3 Storage structures

The next level of sophistication and cost is storage structures, which range from traditional cold frames to full controlled units.

Cold frames. The term "cold frame" is a traditional name for a propagation structure that receives its heat only through absorbed sunlight. When sheltered from direct sunlight and insulated, however, cold frames can be a low-cost alternative for overwinter storage. In northern Alberta and Alaska, cold frames constructed of wooden sideboards lined and topped with rigid Styrofoam™ panels have proven effective for overwintering conifer seedlings (fig. 7.4.8A). Use of insulated cold frames has resulted in a significant increase in plant survival at the Weldwood Nursery in Alberta (Matwie 1991). Cold frames constructed of wooden pallets supported by cement blocks and covered by white plastic polysheeting are considered the most cost effective overwintering system for conifer seedlings at a nursery in Eastern Canada (White 2004).

Cold frames take advantage of the heat stored in the ground, and the insulating covering retards heat loss and,

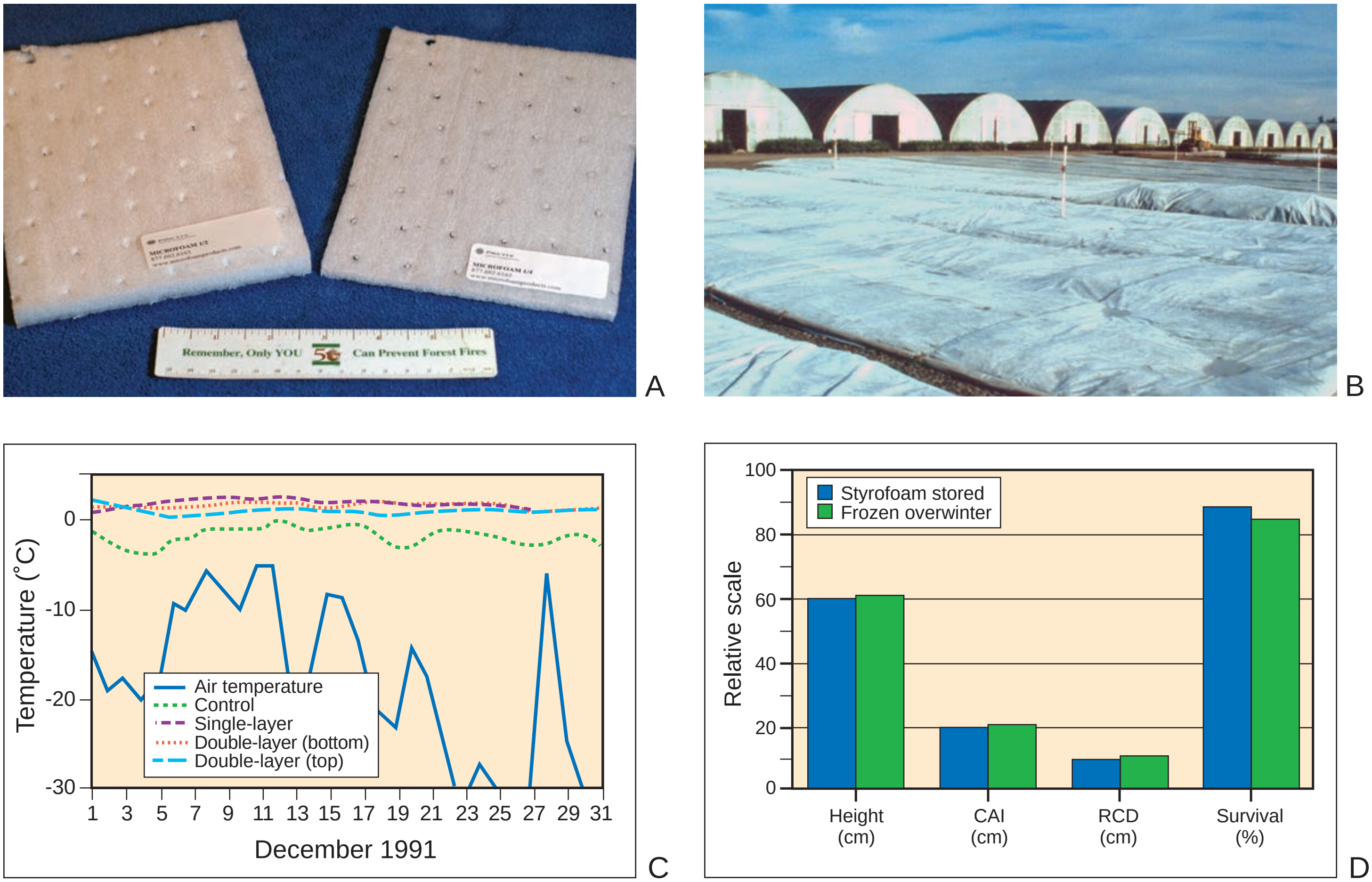
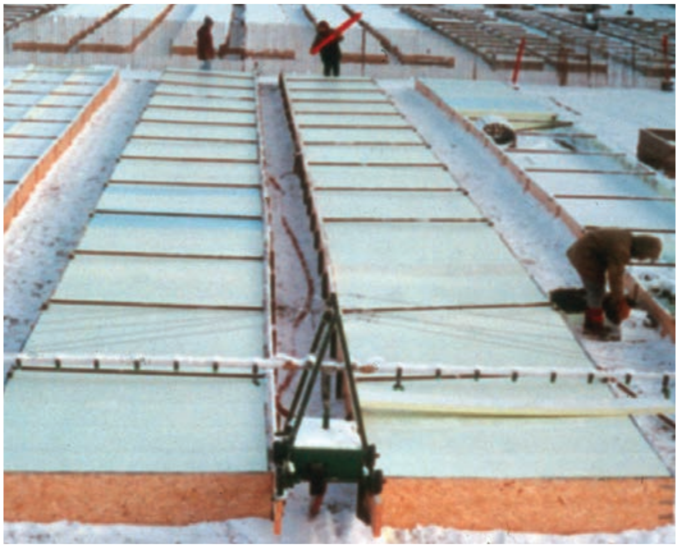


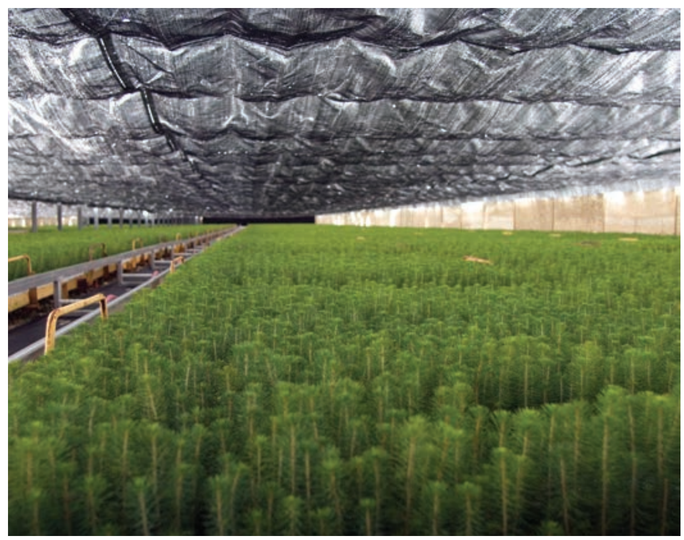
Figure 7.4.7—*Microfoam® plastic foam sheeting makes an excellent overwinter cover (A). Many ornamental nurseries group their containers together on the ground and cover them with Microfoam® (B). When properly designed and applied, Styrofoam™ blankets protected conifer stock as well as refrigerated storage (C&D) (B, courtesy of Richard Regan; C&D, modifed from Whaley and Buse 1994).*



A

B

C



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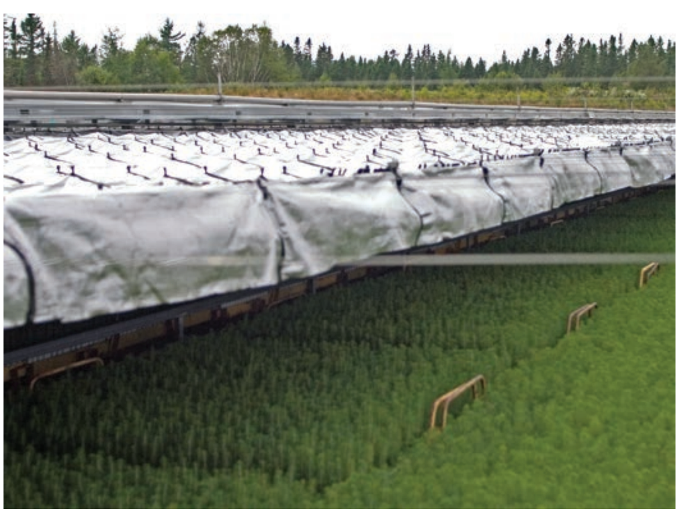


E

Figure 7.4.8—*Cold frames of wood and rigid Styrofoam™ sheet insulation have been used to overwinter container plants in northern climates (A). When weather conditions permit, the top layer of insulation is removed so that plants can be irrigated (B). Cold frames can be extensive (C) and automated to protect plants during freezing temperatures (D) or retracted during heavy snowfall (E) (A&B, courtesy of Larry Matwie; C,D&E, courtesy of J.D. Irving, Limited).*

more important, prevents winter drying. To be most effective, plants should be placed in the cold frames as soon as they are hardy and before the ground freezes. Heat buildup can still be a problem during warm or sunny periods in the winter and, on these occasions, the top insulation panel can be removed for ventilation and to allow irrigation (fig. 7.4.8B). As soon as weather conditions permit in the spring, the tops of the cold frames should be removed to prevent heat buildup and subsequent loss of bud dormancy.

The Juniper Tree Nursery in New Brunswick uses large, sophisticated cold frames to overwinter their stock (fig. 7.4.8C). The accordion-like covers can be extended to protect plants from freezing temperatures or drying winds (fig. 7.4.8D), or opened during heavy snowfall (fig. 7.4.8E). Although expensive to construct, they are much less expensive than refrigerated storage (Brown 2007).

Cloches and polyhouses. These two storage structures are similar except for their length; cloches are shorter and do not offer worker access, whereas polyhouses typically have doors in the end walls. Both feature wooden or pipe frames covered by white plastic sheeting (fig. 7.4.9A) or a panel of Microfoam® placed between two layers of plastic (fig. 7.4.9B). The ends of these structures are opened for cooling during sunny, warm periods during winter (fig. 7.4.9C). Although a single layer of white polysheeting is adequate protection in milder climates, a double layer of white plastic that is inflated by a small fan provides better insulation in colder locations. In locations with frigid temperatures below –18 °C (0 °F), plants overwintered in polyhouses need the additional protection of a white polyfilm or Microfoam® blanket (Perry 1990). In milder climates, growers supply just enough heat in their polyhouses to keep the ambient temperatures just above freezing; this approach has proven effective for overwintering a wide variety of native plants in Colorado (Mandel 2004).

If possible, cloches and polyhouses should be oriented south-to-north to minimize and equalize solar heating. In structures oriented east-to-west, plants on the south side receive more light and heat than those on the north and may require irrigation during the winter. Any closed storage structure needs to be monitored carefully throughout the winter to determine if ventilation is needed on sunny days during late winter and early spring (fig. 7.4.9C).

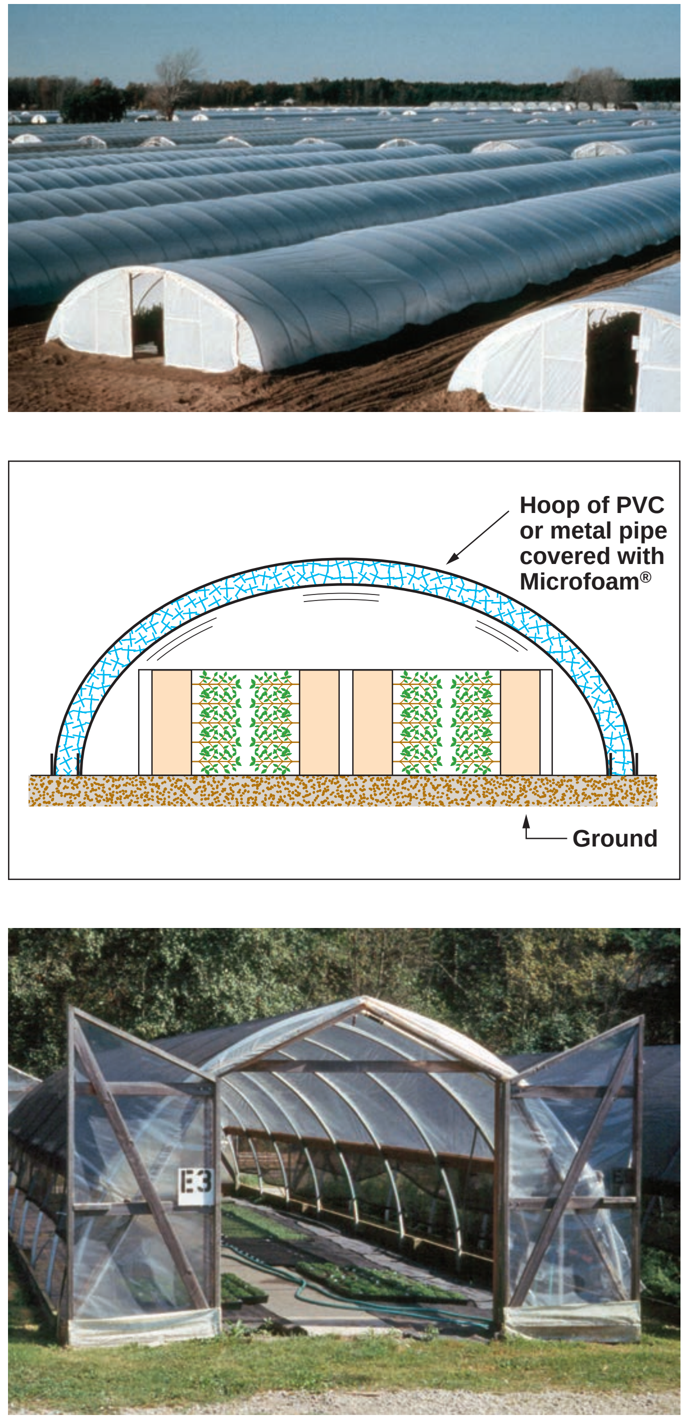


Figure 7.4.9—*Cloches and polyhouses are simple overwintering structures covered with white plastic (A) or Microfoam® sheeting (B). The ends or sides are opened during warm and sunny winter weather for ventilation (C).*

A

B

C

Figure 7.4.10—*Shadehouses are traditional structures that can be used for hardening and then overwintering container stock (A). They are particularly useful for large stocktypes that must be supported by heavy wire racks (B). Before freezing temperatures are expected, the containers should be grouped together on the ground and surrounded by perimeter insulation to protect the roots (C).*

Ventilation can also be provided by opening end doors, or installing a thermostatically controlled fan on one end with intake louvers at the other end. To prevent desiccation, mount fans and louvers in the top of the structures where heat buildup will be greatest.

Shadehouses. Shadehouses are traditional hardening structures that have also been used for overwintering all sizes of container stock (fig. 7.4.10A). They are particularly useful for larger container stock that requires too much space in refrigerated storage. Tall containers like Treepots™ need to be supported, so nurseries have developed heavy wire rack systems. Some nurseries use cement blocks to support prefabricated "stock panels" that can be purchased from ranch or farm supply stores (fig. 7.4.10B).

Shadehouse design varies with nursery climate and location. Where prolonged cold temperatures are not typical, plants can be overwintered under shadecloth or shadeframe. In wet climates, a waterproof roof is desirable for overwinter storage to prevent excessive leaching of nutrients from containers. In areas that receive heavy, wet snowfall, shadehouses for overwinter storage must be significantly stronger than temporary storage structures. Another option is to remove the shade covering during winter to allow the snow to fall through and insulate the crop. Light, dry snow will not damage plants and actually serves as an excellent insulator over the crop.

The typical shadehouse for overwinter storage has shading on both the roof and sides that protects plants from adverse weather, such as high winds, intense rains, hail, and heavy snow. Shadehouse storage reduces seedling temperature below what it would be in direct sunlight by reducing sunlight by about 30 to 50 percent. This shade and the reduced wind speeds significantly lower transpirational water losses; this prevents the scorching known as winter desiccation. To protect sensitive roots, plants are blocked together on the ground and surrounded by an insulating material like sawdust or Styrofoam™ panels (fig. 7.4.10C).

Greenhouses. Very sensitive plants, such as newly rooted cuttings, can be overwintered in a greenhouse with minimal heating to keep air temperatures above freezing. It must be emphasized, however, that greenhouses should

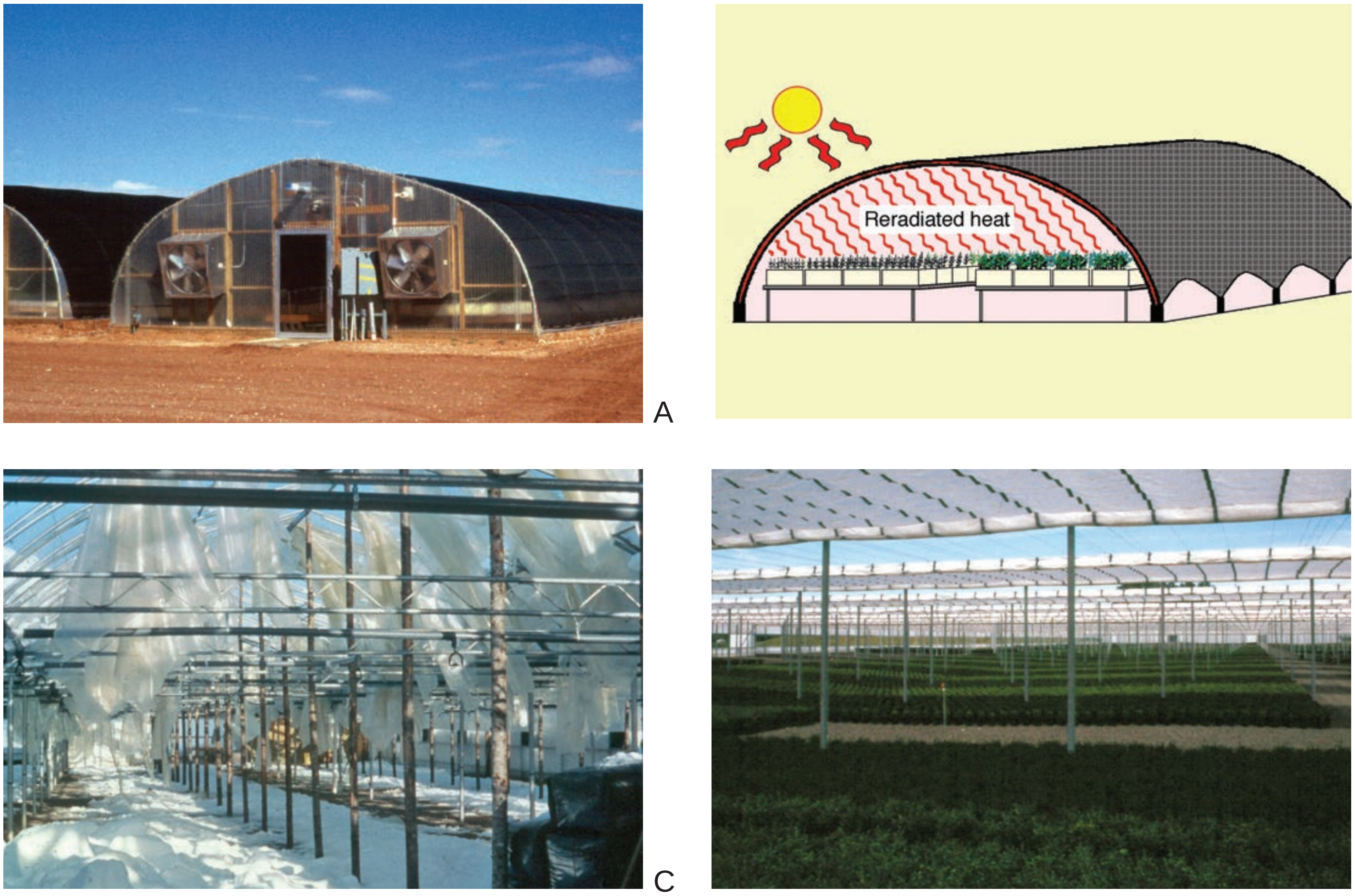


Figure 7.4.11—*Fully enclosed greenhouses are not good for overwintering, especially in climates with sunny winters (A and B). Snow removal is necessary in cold climates (C). Retractable roof greenhouses (D) are better for overwinter storage because they can be opened to allow heat to escape and snow to cover seedlings.*

not be considered for routine overwinter storage, especially in areas with clear sunny winters (fig. 7.4.11A). Greenhouses heatup rapidly during periods of sunny weather, causing plants to rapidly lose dormancy (fig. 7.4.11B). Even if greenhouses are vented, there will be considerable temperature gradients during cold weather. In snowy climates, heat must be used to keep heavy wet snow from building up and damaging the structure (fig. 7.4.11C). On the other hand, retractable roof greenhouses (fig. 7.4.11D) are excellent for overwinter storage because the roof can be opened during sunny weather to allow heat to escape and keep nursery stock dormant. During snowfall, the roof can be left open to allow plants to be covered with a protective layer of snow.

7.4.5 Refrigerated Storage

The basic concepts of refrigeration and design of refrigerated storage are covered in Section 1.3.5.4 of Volume I of this series, so this section will focus on its operational use in forest and native plant nurseries. Refrigerated storage has become the standard in many modern forestry nurseries, especially in the Pacific Northwest, and has been the focus of most storage research.

The two different types of refrigerated storage used in native plant nurseries are cooler storage and freezer storage; they are differentiated by their temperatures (fig. 7.4.12A) and the recommended duration of storage (table 7.4.1). When the photosynthetic recovery of cooler- and freezer-stored plants after outplanting was monitored, differences were minimal (fig. 7.4.12B). A review of nursery research and operational experience shows that cooler storage is best for periods of 2 months or less, whereas freezer storage is recommended for longer storage periods. Cooler storage is preferred when nursery stock is outplanted throughout the winter. For example, in the Southern States, cooler storage periods vary from a week or less in the late summer or fall to as long as 3 months (Dumroese and Barnett 2004). Although no research has been published on the subject, operational experience has shown that many broadleaved trees and shrubs store better in coolers (Davis 1994) (fig. 7.4.12B), and many other native plant species can be stored this way as well (table 7.4.2). Some species, such as black walnut (*Juglans nigra*) and dogwood (*Cornus* spp.), have serious problems with root rot in cooler storage. Considerable variation exists between species, however, so there is no substitute for practical experience.

Freezer storage has become the standard operating procedure for many commercial conifer nurseries (Hee 1987; Kooistra 2004), but less is known about how other native plants tolerate it. Because plant carbohydrate reserves decrease during cooler storage, freezer storage is recommended for storage durations longer than 2 months; even so, 6 to 8 months appears to be the practical limit for freezer storage (Ritchie 2004). Although carbohydrate reserves are conserved better with freezer storage, the primary reason for choosing freezer storage is the reduced incidence of storage molds. Because freezing converts all the free water in the storage container to ice, the development of pathogenic fungi such as gray mold (*Botrytis cinerea*) is retarded (Trotter and others 1992). After packing, plants should be frozen as quickly as possible to minimize carbohydrate loss and reduce the possibility of mold development (Kooistra 2004).

To ensure good air circulation in the storage unit, boxes of nursery stock are loaded onto pallets and then stacked onto shelving (fig. 7.4.13A) to improve air flow and prevent heat buildup. Refrigerated vans ("reefers") are sometimes used for temporary storage (fig. 7.4.13A) but are prone to breakdown and therefore are no substitute for well-designed refrigeration units.

7.4.5.1 Physiology of plants in refrigerated storage

Although refrigeration is the most expensive way to store nursery stock, it offers significant physiological advantages over other methods. As shown earlier (fig. 7.4.2), refrigerated storage can even increase the quality of stored plants. Camm and others (1994) present an excellent overview of the subject, although the authors do not always distinguish between bareroot and container stock. Ritchie (1987) is also informative. More information on all aspects of seedling quality can be found in Chapter 7.2.

Table 7.4.1—*Comparison of types of refrigerated storage*

Type of storage	In-container temperature	Recommended length of storage	Best type of packaging
Cooler storage	1 to 2 °C (33 to 36 °F)	2 weeks to 2 months	Kraft-polybags or cardboard boxes with plastic bag liners
Freezer storage	–2 to –4 °C (30 to 25 °F)	2 to 8 months	Cardboard boxes with plastic bag liners

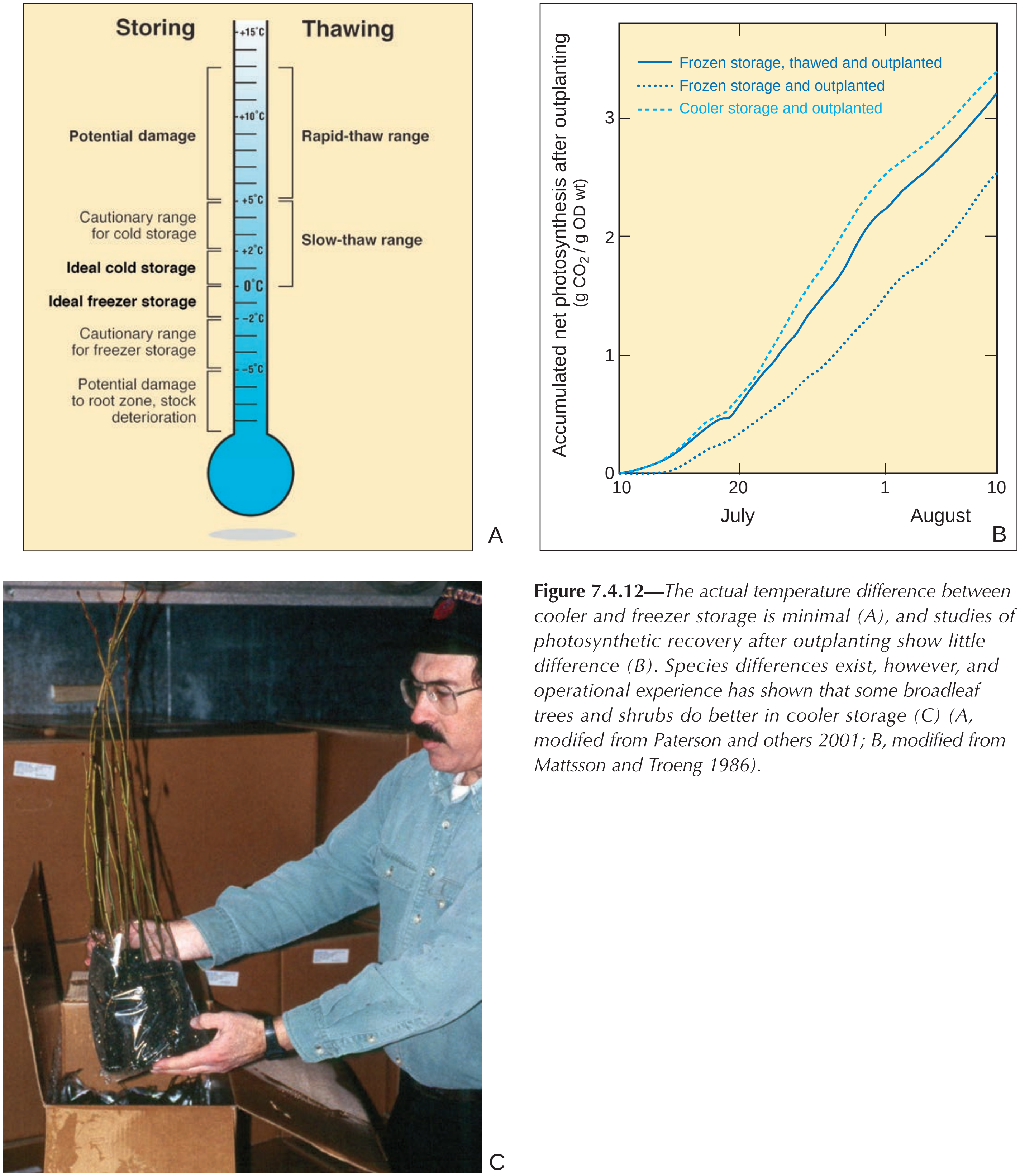


Figure 7.4.12—*The actual temperature difference between cooler and freezer storage is minimal (A), and studies of photosynthetic recovery after outplanting show little difference (B). Species differences exist, however, and operational experience has shown that some broadleaf trees and shrubs do better in cooler storage (C) (A, modifed from Paterson and others 2001; B, modified from Mattsson and Troeng 1986).*

Table 7.4.2—*Nontimber native plant storage at Coeur d' Alene Nursery varies with species and outplanting window (Burr 2004)*

Scientific name	Common name	Packaging	Type of storage	Outplanting window
Alnus rubra	Red alder	Pull, bag, and box	Freezer	Spring outplant
Alnus sinuata	Sitka alder	Pull, bag, and box	Freezer	Spring outplant
Amelanchier alnifolia	Serviceberry	Pull, bag, and box	Freezer	Spring outplant
Arctostaphylos uva-ursi	Kinnikinnick	Pull, bag, and box	Cooler	Spring outplant
Arctostaphylos uva-ursi	Kinnikinnick	Overwinter in greenhouse	Cooler	Spring regrowth, summer/fall outplant
Ceanothus velutinus	Snowbrush	Overwinter in greenhouse	Cooler	Spring regrowth, summer/fall outplant
Menziesia ferruginea	Fool's huckleberry	Overwinter in greenhouse	Cooler	Spring regrowth, summer/fall outplant
Rosa woodsii	Woods' rose	Pull, bag, and box	Freezer	Spring outplant
Rosa woodsii	Woods' rose	Pull, bag, and box	Cooler	Spring outplant
Rosa woodsii	Woods' rose	Overwinter in greenhouse	Cooler	Spring regrowth, summer/fall outplant
Salix spp.	Willows	Pull, bag, and box	Freezer	Spring outplant
Spirea betufolia	White spirea	Pull, bag, and box	Cooler	Spring outplant
Spirea douglasii	Rose spirea	Pull, bag, and box	Cooler	Spring outplant
Symphoricarpus albus	Snowberry	Pull, bag, and box	Freezer	Spring outplant
Xerophyllum tenax	Beargrass	Overwinter in greenhouse	Cooler	Spring regrowth, summer/fall outplant

Dormancy. Most research has been done on bud dormancy, and its intensity is measured by days to bud break (DBB). Refrigerated storage temperatures can partially satisfy the chilling requirement of dormant stock (Burr and Tinus 1988) and then prolong the release of dormancy until later in the spring (Dunsworth 1988). Several studies have proven that freezer storage is as effective as cooler storage in releasing dormancy (fig. 7.4.14A), provided plants have reached a certain level of cold hardiness prior to storage. In one study with white spruce (*Picea glauca*) (Harper and others 1989), dormancy release in freezer storage continued for as long as 6 months. Cooler storage and freezer storage maintain dormancy equally, and plant performance after outplanting appears to be similar. For example, when the photosynthetic recovery of Scots pine (*Pinus sylvestris*) seedlings stored in cooler or freezer storage was measured during the first season after outplanting, little difference was noted in outplanting performance (Mattsson and Troeng 1986).

Cold hardiness. Obviously, nursery stock must be cold hardy to tolerate overwinter storage, but the operational importance of cold hardiness is its relationship to overall stress resistance. Cold hardiness tests are routinely used as a storability index (see Chapter 7.2). Exactly how refrigerated storage affects the development or maintenance of cold hardiness is an important question but, unfortunately, little research has been published on container plants. In one test, interior spruce seedlings in freezer storage initially gained more cold hardiness but then lost up to half their hardiness by the end of the storage period (fig. 7.4.14B).

Stress resistance. This quality attribute reflects a plant's overall tolerance to the many physical and physiological stresses during harvesting, storage, shipping, and outplanting. Again, little research has been done with container stock, but Douglas-fir seedlings stored under refrigeration showed improved tolerance to low temperatures, root desiccation, and handling stresses (Ritchie 1986).

Root growth potential (RGP). Most studies of new root growth of plants under refrigerated storage show variable results with no discernable trends. For example, when white spruce seedlings were removed from freezer storage at intervals through the winter and were potted to observe new root growth, RGP was found to increase for 3 to 4 months and then to decrease (fig. 7.4.14C) (Harper and others 1989). This agrees with Mattsson and Lasheikki (1998) who found that RGP of Siberian larch (*Larix sibirica*) container stock decreased after about 4 months of refrigerated storage.

Stored carbohydrates. After plants are harvested and placed in dark, refrigerated storage, they begin to use stored carbohydrates, even in freezer storage (fig. 7.4.14D). Carbohydrate reserves are measured as total nonstructural carbohydrates (TNC) as opposed to structural carbohydrates, which cannot be used for energy. Ritchie (2004) estimated that conifer seedlings contain from 15 to 20 percent dry weight of TNC when they are harvested, and they gradually decrease during refrigerated storage. Obviously, the longer plants are stored under refrigeration, the less energy reserves they have for survival and growth after outplanting. Because of species differences and the wide variation of outplanting site conditions, the lower limit for TNC varies significantly. Coastal sources of Douglas-fir seedlings are in a critical area when they reach 10 to 12 percent of total dry weight (Ritchie 2004).

A

B

Figure 7.4.13—*To ensure uniform temperatures throughout the refrigerated storage units, boxes must be spaced on shelving to allow good air flow (A). Portable reefer vans (B) should be used only for short-term refrigerated storage.*

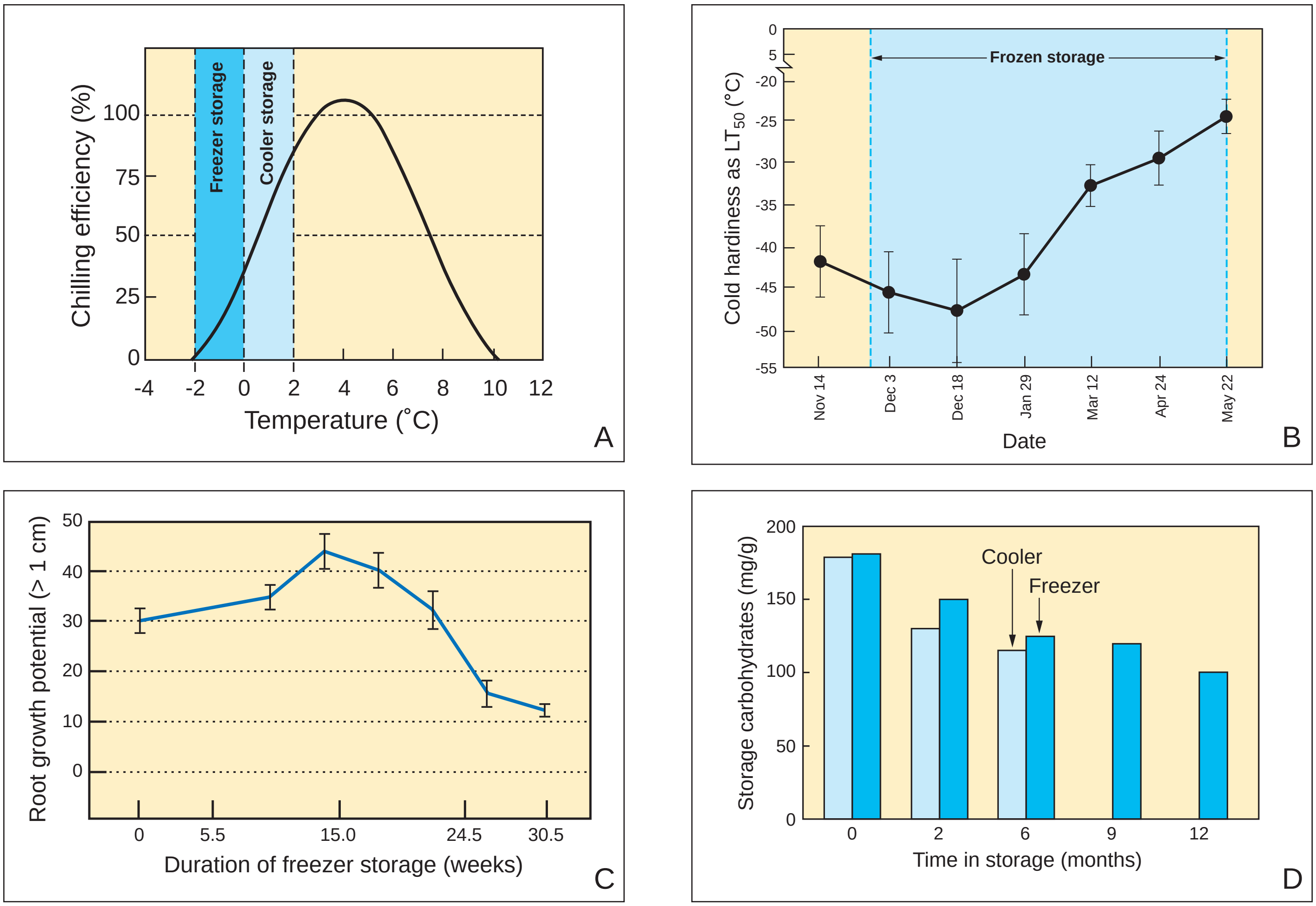


Figure 7.4.14—*Cooler and freezer storage are effective in fulfilling the chilling requirement after plants have attained a certain level of cold hardiness (A) and also have other effects on plant physiology. Compared with outside storage, conifer seedlings maintained their cold hardiness better under refrigeration (B). Root growth potential increased for about 4 months, and then declined (C). Freezer storage slows the decline in stored carbohydrates more than cooler storage and so is preferable for long-term storage (D) (A, from Ritchie 2004; B, modified from Grossnickle and others 1994; C, modified from Harper and others 1989; D, modified from Ritchie 1982).*

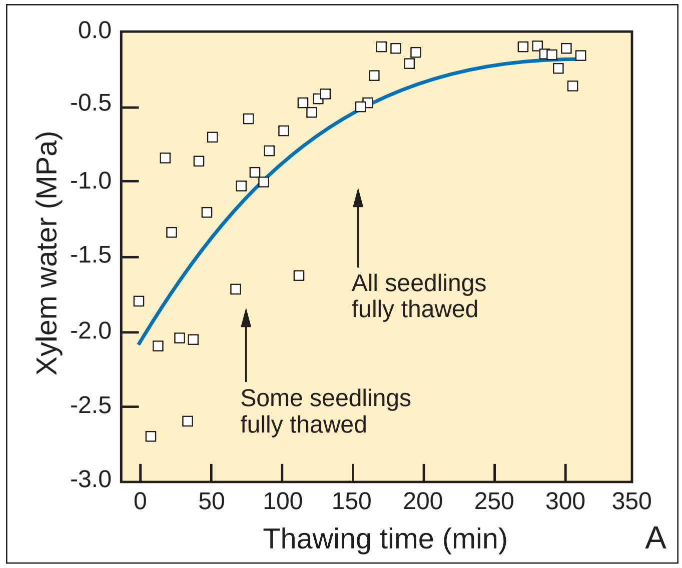
7.4.5.2 Handling, thawing, and outplanting frozen stock

For many nursery clients, freezer storage is a relatively new practice and some clients have expressed concern about whether frozen stock can be safely transported. Experience with commercial conifers has shown that frozen seedlings can be shipped without serious injury (Kiiskila 1999), but, like all stock, frozen stock should always be handled with care.

The speed at which frozen plants are thawed has also caused concern with many nursery customers. Initially, slowly thawing frozen stock was considered best, but rapid thawing is now gaining support. In the most comprehensive experiments to date, Camm and others (1995) studied the physiological effects of thawing regimes on the physiology of container spruce seedlings. They found no significant differences between rapid (1 to 2 days at 15 °C [60 °F]) and slow thawing (17 days at 5 °C [41 °F]). For instance, seedling moisture stress was found to recover in only 4 to 5 hours during rapid thawing (fig. 7.4.15A). These positive results were confirmed by operational trials in British Columbia (Silim and Guy 1998) that showed rapid thawing of frozen stock (15 °C [60 °F] for 1 to 2 days) resulted in less carbohydrate loss and produced better out-planting performance (fig. 7.4 15B). The Nursery Technology Cooperative at Oregon State University did a similar study and found no significant difference between slow or rapid thawing periods or for stock that was rapid thawed and then held in cold storage (Rose and Haase 1997). In one of the most well-designed and long-term studies, freezer-stored Norway spruce container stock was thawed in cardboard boxes at 39 or 54 °F (4 or 12 °C) for up to 16 days before outplanting. When outplanting survival was measured after 3 years, the best thawing temperature was 12 °C (54 °F) for 4 to 8 days, which also prevented mold development (Helenius and others 2005). Based on this research, rapidly thawing frozen stock for several days at (50 to 60 °F) can be recommended.

Obviously, common sense must be applied and thawing should be done out of direct sunlight, but it seems that the quicker the thaw, the better. The problem of increased susceptibility to storage molds is a rather specious concern, because fungal growth will be slow in cold storage.

Changing weather can shut down outplanting projects very quickly, which raises the question about what to do with the thawed plants. No research has been published on this problem, but Ritchie (2004) recommends cooler storage if the delay will be only a few days but freezing the stock if several weeks will elapse. The very latest research involves the direct outplanting of still-frozen seedlings. Comparison outplantings showed that when frozen container stock was planted, it thawed rapidly without any significant effects on plant growth (Kooistra and Bakker 2002, Islam and others 2008). This can pose an operational challenge, however, because freezer storage usually results in plants freezing together to form one large mass. Therefore, direct outplanting of frozen stock cannot be accomplished unless plants can be easily singulated.



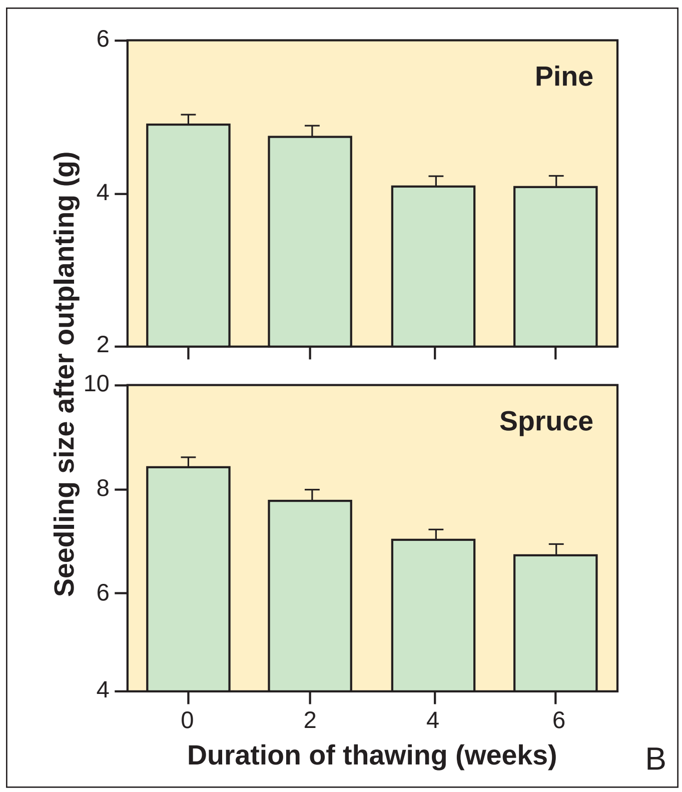


Figure 7.4.15—*Although slow thawing of frozen nursery stock was initially favored, rapid thawing has been proven to have no adverse affects in terms of plant moisture stress (A) or other physiological variables. Outplanting trials have confirmed that rapid thawing is actually beneficial to seed-ling growth (B) (A, modified from Camm and others 1995; B, modifed from Silim and Guy 1998).*

7.4.6 Monitoring Plant Quality in Storage

During overwinter storage, plants can be considered as being in a state of "suspended animation"—the plants are alive but their physiological functions have slowed to a minimum. The critical limiting factor that maintains dormancy during storage is temperature. Therefore, temperature should be rigorously monitored throughout the overwinter storage period (Kooistra 2004). Electronic thermometers with long probes are very useful for monitoring temperature in storage containers (fig. 7.4.16A). Small and inexpensive data loggers are self-contained recording devices that monitor temperature, humidity, and other weather variables that contribute to plant stress (fig. 7.4.16B). New models like the Hobo® are small enough to place in storage packages where they detect both incidence and duration of exposure (McCraw 1999). Thermochron iButtons® are even smaller and almost indestructable (Gasvoda and others 2003). Both can monitor temperature over time and the data can be downloaded to a computer (fig. 7.4.16C). Any thermometer or temperature recording device must be calibrated annually to make sure it is accurate; an easy way to do this is to place the temperature probe in a mixture of ice and water and the temperature should read exactly 0 °C (32 °F) (fig. 7.4.16D).

It is important to measure temperature within the containers as well as in the storage building, because the two locations tell different things. Because stored plants are still respiring, they generate a small amount of heat, which means that the in-bag or in-box temperature will always be a couple of degrees warmer than the ambient environment. For this reason, the setpoint temperature for the storage environment should always be 1 to 2 degrees cooler than the desired temperature in the container (Kooistra 2004). For example, you may have to operate with a setpoint of –2 °C (28 °F) to obtain a temperature of –1 °C (30 °F) in-box temperature. The temperature in the storage facility should be monitored as well, because it tells whether the compressors are working properly and good distribution of cold air is occurring (Landis 2000).

After temperature, the next most critical factor to monitor is moisture. Even hardy, dormant plants can dry out during overwinter storage. This is more of a concern with evergreen species because they will begin to transpire whenever exposed to heat and light. As mentioned earlier, desiccation is a continual threat in refrigerated storage, especially freezer storage. Even deciduous species can be damaged, so it is important to check plants occasionally during the storage period and to irrigate, if necessary. Because water is so heavy, weighing storage boxes is the most accurate way to monitor moisture loss during storage. Many nurseries measure plant moisture stress with a pressure chamber prior to and during harvesting (see Chapter 7.2); this equipment also affords a quick and accurate way for monitoring the degree of plant desiccation during storage (Landis 2000).

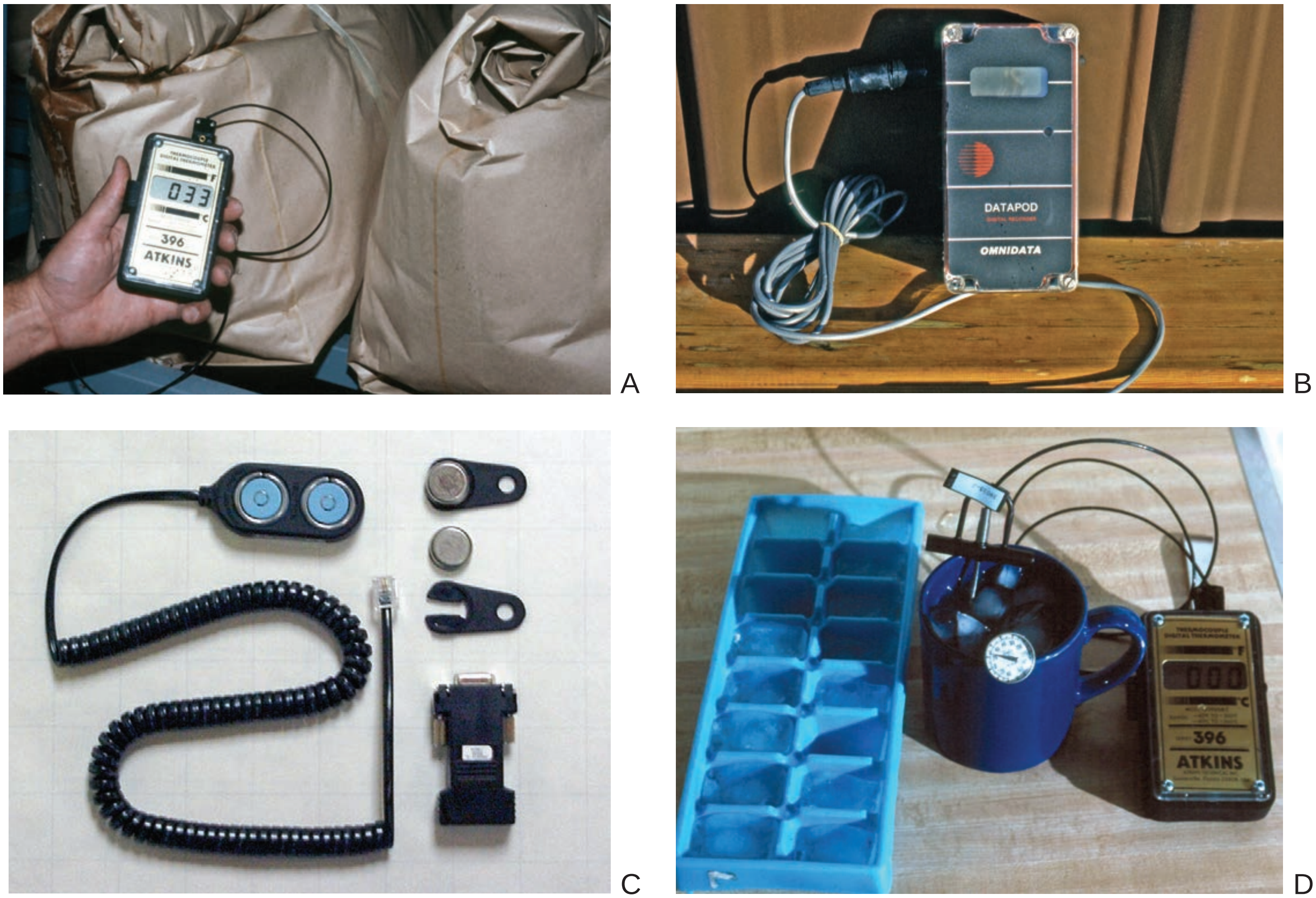


Figure 7.4.16—*Temperature can be monitored with long-stemmed electronic thermometers (A). Small hygrothermographs like the Datapod® can monitor both temperature and relative humidity (B). Even smaller, the iButton® can monitor temperature for weeks or months, and the data can be downloaded to a computer (C). Calibrate any thermometer in a water and ice mixture to make sure it is accurate (D).*

7.4.7 Causes of Overwinter Damage

Overwinter storage has many potential hazards for stored plants (table 7.4.3), and growers should periodically monitor stock for the following hazards.

7.4.7.1 Cold injury

Cold injury can develop from a single frost or during an extended period of cold weather. Damage is most common in the late fall or early spring, when plants are entering or coming out of dormancy. Cold injury is directly related to plant dormancy or cold hardiness. The shoots of native plants that have been properly hardened can tolerate freezing temperature extremes expected in the geographic area from which they originate, but cold hardiness and dormancy are lost as winter progresses. The lateral meristem at the root collar can be injured by frost (fig. 7.4.17A), as can the buds. This type of injury is very difficult to diagnose without destructive sampling, because symptoms may not become evident until later in the spring.

Root systems need special protection because they are injured at much higher temperatures than shoots. Furthermore, young fibrous roots are less hardy than older woody roots and will be injured at higher temperatures. Rooted cuttings are particularly vulnerable to injury because their roots have not yet developed protective layers. Young roots are typically on the outside of the container and are the first to be injured by cold temperatures (fig. 7.4.17B). Where freezing temperatures occur, cold injury to roots is the most common type of overwinter damage. Because shoots do not show symptoms immediately, root injury often goes unnoticed and the damage becomes evident after outplanting. Therefore, growers should design their overwintering systems to protect all roots from damaging temperatures during overwinter storage.

7.4.7.2 Desiccation

Winter drying is actually desiccation injury and occurs whenever plants are exposed to extreme moisture stress, especially wind and/or direct sunlight (fig. 7.4.17C). Damage is most severe when the growing medium and roots remain frozen for extended periods while the shoots are exposed to sun and wind. Plants can even become desiccated when they are stored under frost-free refrigeration without proper packaging. Winter drying is not directly related to plant dormancy or cold hardiness—even the most dormant and hardy stock can be damaged. Plants stored near the perimeter of open compounds or sheltered storage are most susceptible (fig. 7.4.17D), but even plants covered by snow can be damaged if their tops become exposed. This type of desiccation can be prevented if open or shelter-stored stock can be irrigated during the winter storage period and if effective perimeter insulation is used.

7.4.7.3 Loss of dormancy

Loss of dormancy happens most often when container stock is overwintered in greenhouses. During winter periods of clear, sunny weather, greenhouses can heat up and cause plants to lose dormancy. Loss of dormancy becomes progressively more serious during late winter and early spring, when plants have fulfilled their chilling requirements and cold temperatures are the only thing keeping them from growing (fig. 7.4.17E). Although refrigerated storage is the best prevention, using white or reflective coverings in structureless storage minimizes the effects of sunlight and prevents heat buildup. Monitor the temperature frequently in sheltered storage and ventilate if necessary.

7.4.7.4 Storage molds

The type of storage conditions will determine the types of disease problems that may be encountered. Although fungal diseases can be a problem in open storage or shadehouses, they are most serious when plants are overwintered under refrigeration (table 7.4.3). Some fungi, such as *Botrytis cinerea*, actually prefer the cold, dark conditions in storage bags and boxes and will continue to grow and damage plants whenever free moisture is available (fig. 7.4.17F). Some nurseries apply fungicides before overwinter storage, but careful grading to remove injured or infected plants is the best prevention. Freezer storage has become popular because it prevents the further development of storage molds. Much more information is provided in Section 5.1.6 in Volume Five of this series.

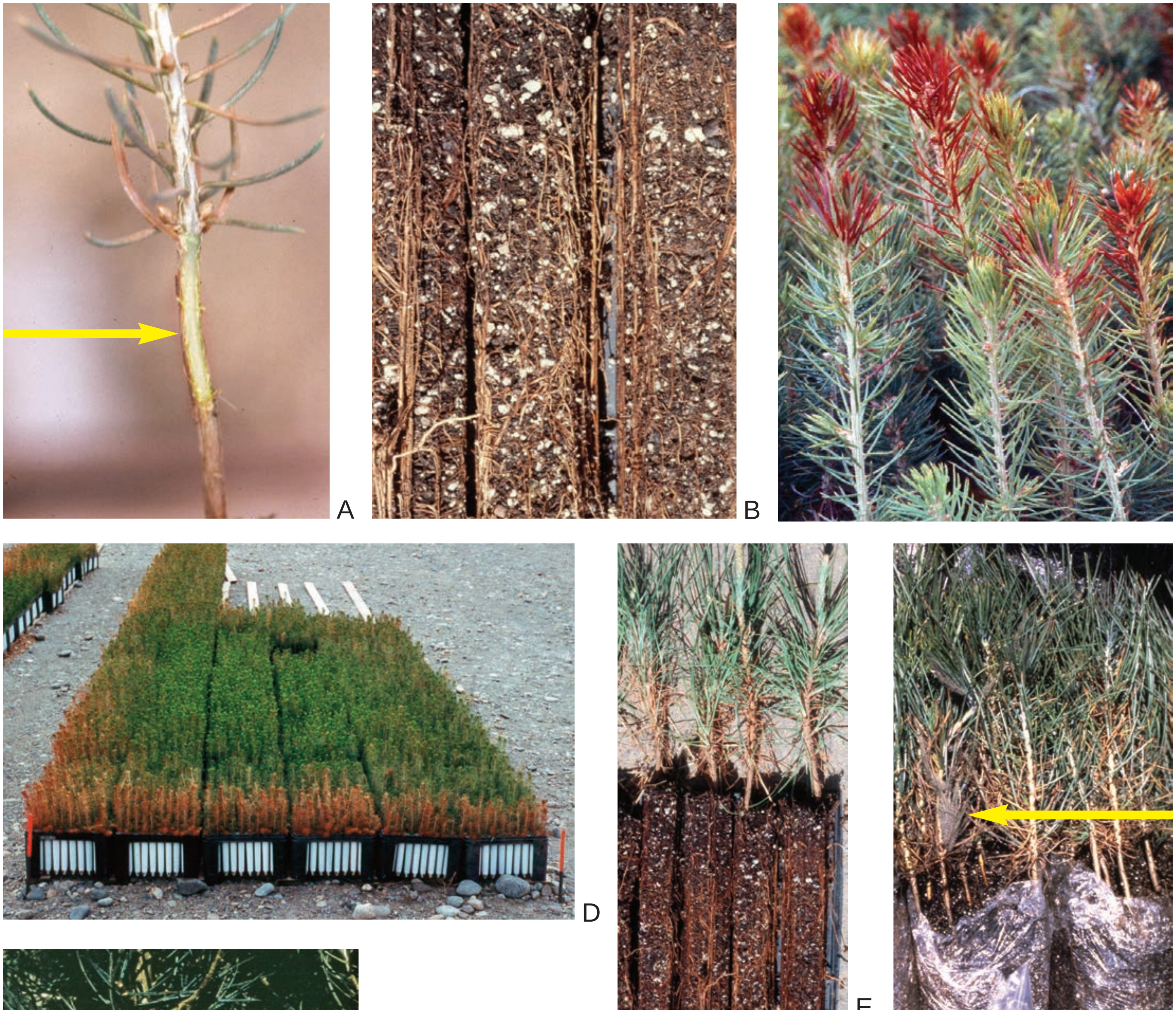


Figure 7.4.17—*Overwinter storage is a time of considerable risk for nursery stock. Cold temperatures can damage nonhardy tissue, such as the lateral meristem (A). Roots are particularly susceptible because they will grow whenever temperatures permit (B). Winterburn (C) is actually desiccation and is particularly severe around the perimeter of storage areas (D). Overwintered plants gradually lose dormancy and can break bud during late winter or early spring (E). Storage molds (F) are most serious in cooler storage, whereas animal damage can be a real problem in sheltered storage (G).*

7.4.7.5 Animal damage

The only type of overwinter storage where animals will not pose a threat is refrigerated storage. Small rodents, such as mice and voles, can be pests in shadehouses and structureless systems (fig. 7.4.17G), because the pests are protected from natural predators and from harsh weather conditions. Baiting or trapping to keep populations low can be effective if started early in the season. Large animals, such as deer and rabbits, can be pests in open, structureless, and shadehouse storage, but fencing is an effective way to prevent damage. See section 5.1.6 in Volume Five of this series for more specific information.

Table 7.4.3—*Plants can be injured by several types of stresses during overwinter storage*

Type of damage	Cause	Preventative measures for types of storage		
		Open	**Sheltered**	**Refrigerated**
Cold injury (fig. 7.4.17A-B)	Temperatures below plants' cold hardiness level Roots are much more susceptible than shoots	Properly harden plants to tolerate maximum expected cold temperatures		
Drought injury (Winter desiccation) (fig. 7.4.17C-D)	Exposure to intense sunlight and especially drying wind	Fully saturate media before storing		
		Shade plants and protect from wind	Cover stock with moisture-retaining film	Use moisture-retentive packaging
Loss of dormancy (fig. 7.4.17E)	Temperatures above 5 °C (40 °F)	Not possible	Monitor and ventilate as needed	Maintain cold in-box temperatures.
Storage molds (fig. 7.4.17F)	Warm temperatures; latent infections of *Botrytis*	Prevent injury to plant tissue; cull damaged plants		
		Keep foliage cool and dry	Keep foliage cool and dry	Use freezer storage if stored more than 2 months
Animal damage (fig. 7.4.17G)	Small rodents and even rabbits can girdle stored nursery stock	Exclude larger animals with fencing; use poison bait for rodents		Not a problem

7.4.8 Summary and Conclusions

Nondormant plants destined for nearby outplanting may go from the nursery to the field with little or no storage (hot-planted). More commonly, dormant plants are stored during winter until they can be outplanted. Storage becomes more important as the distance from the nursery to the outplanting sites increases, differences between climates at the nursery and field sites are great, and nurseries produce large quantities of plants requiring months to process. Therefore, storage is an operational necessity rather than a physiological requirement.

Overwinter storage should be developed to meet local climate, plant type, and production factors. In general, three types of overwinter storage are used: open, structureless, and structured. In open storage, plants are left outdoors, on the ground, and are protected from sun and wind by larger trees and snowfall. Plants stored in a structureless system are also outdoors and on the ground, but they are protected from the vagaries of winter weather by various applications of plastic and/or Styrofoam™ sheets. Structured storage can be very simple, such as a cold frame, progressing through modest structures, such as polyhouses and shadehouses that provide some climate control, to the most complex systems—refrigerated units. Refrigerated storage includes coolers (temperatures just above freezing), which are best for short-term storage of plants (2 weeks to 2 months), and freezer storage (temperatures just below freezing), which is best for long-term storage (2 to 8 months).

Regardless of the type of storage used, plants should be regularly monitored to ensure that pests (animals and storage molds) are not becoming a problem, temperatures are in the proper range to keep plants dormant, and medium moisture is appropriate to avoid desiccation.

After storage, plants should be shipped carefully to the field. Stock kept in freezer storage can be safely shipped while still frozen, but if thawed at the nursery, the thawing process should be rapid to reduce carbohydrate losses and development of storage molds.

Successful storage of container plants is one of the most challenging and important aspects of nursery management. Many types of overwintering systems can be employed, depending on location, climate, and species grown; more than one system may be used at a nursery. Determining when it is safe to harvest plants so that they will maintain a high level of quality throughout the storage period and to the outplanting site is one of the most challenging aspects of nursery management.

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