Harvesting, Storing, and Shipping

Thomas D. Landis and Tara Luna

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Plants are ready for harvest and delivery to clients after they have reached target specifications (see Chapter 2, *The Target Plant Concept*) and have been properly hardened (see Chapter 12, *Hardening*). Originally, nursery stock was grown in soil in fields; nursery managers would "lift" those seedlings out of the ground to harvest them. That traditional nursery term is still used today, and we refer to the traditional "lifting window" (usually late autumn to very early spring) as the time period during which plants are at maximum hardiness, most tolerant to stress, and therefore in the best condition for harvesting.

SCHEDULING HARVESTING: THE "LIFTING WINDOW"

Just 50 years ago, the process of harvesting, storing, and shipping native plants was much simpler than it is today. Conifer trees were the main native plants used for restoration after fire or logging. Seedlings were grown bareroot and the traditional lifting window described above allowed foresters to have plants in time for the traditional "outplanting window," which was always springtime. Now, container stock allows a much wider planting window so plants can be outplanted almost year-round if site conditions are favorable (table 13.1). For example, in northern Idaho, native plants can be outplanted starting in February at the lowest elevations through July at the highest elevations, and, if autumn rains are sufficient, again in September and October. Still, most container stock is outplanted in the spring, when soil moisture and temperature are most favorable for survival and growth.

Packaging seedlings for storage by R. Kasten Dumroese.

This potential variety in outplanting times makes defining the lifting window and scheduling harvesting more difficult. Our primary focus in this chapter will be on lifting plants during the more traditional season (autumn through early spring) because storage, shipping, and outplanting require special techniques. Summer and fall lifting is discussed in the *Special Outplanting Windows* section found near the end of this chapter.

In native plant nurseries, four different methods of scheduling seedling harvesting have been used: calendar and experience, foliar characteristics, time and temperature, and seedling quality tests.

1. Calendar and Experience

Scheduling harvesting according to the calendar is the most traditional technique, and, when based on the combined experience of the nursery staff, can be quite effective. The procedure is simple: if it takes 4 weeks to harvest the plants, then that amount of time is scheduled on the calendar. The dates are selected based on past weather records and how well plants harvested on those dates have survived and grown after outplanting.

A good rule of thumb is to use the frost date (Mathers 2004). To estimate the autumn frost date, take the average date of the first frost in autumn and add 30 to 45 days before that. The spring frost date, which is calculated as 30 to 45 days before the last average frost, can be used to determine when to uncover plants in spring.

2. Foliar Characteristics

Native plant growers use several morphological indicators to help them determine when plants are

Figure 13.1—*(A and B) When plants are ready to harvest, the foliage changes color and becomes more hardy. (C and D) Many woody plants form firm dormant buds with overlapping scales.* Photos by Thomas D. Landis.

Table 13.1—If outplanting site conditions are favorable, container plants can be planted year-round

Region	Potential Outplanting Windows	Outplanting Conditions
Northeast	April and May	Typical spring outplanting
Rocky Mountains (high elevations)	June and July	Good soil moisture and warmer soil temperatures; spring access prohibited by snow
Southwest	July and August	Coincides with summer rains
Northern California	September and October	Adequate soil moisture exists; poor spring access
Southeast	November through February	Outplanting conditions favorable throughout winter
Pacific Northwest	February and March	Typical late winter outplanting

becoming hardy, including changes in foliage, buds, and roots.

Foliar Changes

All plants give visual cues when they are dormant and hardy enough to harvest. With grasses and sedges, the chlorophyll dies, so foliage becomes straw colored (figure 13.1A). The leaves of deciduous woody shrubs and trees also change color, from yellows to reds, depending on the species (figure 13.1B). Even evergreen plants show signs when they are becoming dormant. For example, the cuticle of leaves or needles becomes thicker and waxier so that the seedling can tolerate desiccation during winter. Experienced growers can feel when plants are becoming hardy and the needles of some species even show a slight change in color. In spruces, the actively growing foliage is bright green whereas dormant foliage becomes bluer in color because of the waxy cuticle that develops on the surface (figure 13.1C).

Buds

Plants of many native plant species form a bud at the end of the growing season and many people look for large buds with firm bud scales as an indication of shoot dormancy (figure 13.1D). However, some species with indeterminate growth patterns (junipers, cedars) do not form a dormant bud.

Presence of White Root Tips

Roots never truly go dormant and will grow whenever soil temperatures are favorable, so the presence or absence of white roots should not be used as an indication of when harvesting should begin.

3. Time and Temperature

The technique of accumulating "chilling hours" is intuitive; plants need a certain amount of exposure to cold before they can be harvested. Therefore, the cumulative exposure of plants to cold temperatures should help indicate when they are becoming dormant and hardy. The chilling hours technique is relatively simple: record the daily temperatures, calculate the chilling hours, and then correlate this numerical index to some measure of seedling quality, such as outplanting performance. Inexpensive temperature loggers are available that will calculate chilling hours directly. Plants are harvested over the duration of the potential lifting season and outplanted to determine survival and growth. Because chilling hours will vary from year to year, data should be gathered for at least 3 to 5 years. Seedling performance data are then plotted against the accumulated chilling hours, and the resulting graph shows when it is safe to begin harvesting the plants.

4. Seedling Quality Tests

Larger forest nurseries use cold hardiness tests as an indication of storability. Plants are placed in a programmable freezer and taken down to the predetermined temperature threshold of 0 °F (-18 °C). After a period of exposure, the plants are placed in a warm greenhouse and evaluated for cold injury to the foliage or cambium. A modification of this technique could be used for other native species.

HARVESTING OR LIFTING

In container nurseries, the process of harvesting consists of two contiguous operations: grading and packing.

Grading

This operation consists of evaluating plant size and quality and removing plants ("culls") that are outside the size specifications or are damaged or deformed (figure 13.2A). Culls that are damaged or diseased are discarded or, better yet, incorporated into the compost pile. Plants that are just too small can be held over for additional growth but usually must be transplanted into larger containers.

Typical grading criteria include size measurements such as shoot height and stem diameter at the root collar, which is known as "caliper" (figure 13.2B). Plants that meet size and quality standards are called "shippable," and they are counted to establish an accurate inventory; the inventory should be shared with the client or person in charge of outplanting.

Packing

This next step in the harvesting process depends on how plants will be stored and shipped. The two options for packing include (1) plants remain in their containers or (2) plants are extracted and placed in bags or boxes and refrigerated or frozen. Large container stock (> 1 gal) is typically stored and shipped in their growth containers but smaller plants can be removed from their containers. The type of processing depends on the type of container. With single-cell containers, the culls are removed from the racks and replaced with shippable plants, a process known as "consolidation." Containers are then stored on the ground in a shadehouse until they are shipped to the field. With block containers, however, cull plants are difficult to remove, so larger nurseries extract the shippable plants, wrap or bag them, and place them in bags or boxes for refrigerated storage, a practice known as "pull and wrap" (figure 13.2C).

PLANT STORAGE

Unlike many other products that can be stored for extended periods without a decrease in quality, nursery crops are living and have a very limited shelf life. Therefore, well-designed seedling storage facilities are needed at all native plant nurseries. Seedling storage is *an operational necessity, not a physiological requirement* because of the following conditions:

1. Traditionally, forest nurseries were located at great distances from outplanting sites, and refrigerated storage was needed to preserve plant quality and to facilitate shipping. Tribal nurseries, however, are more local and closer to where stock will be outplanted, so sophisticated storage facilities may not be needed.
2. The lifting window at the nursery may not coincide with outplanting windows on all the various sites. This scenario is particularly true in mountainous areas where nurseries are located in valleys with much different climates than what project sites at higher elevations have. If a client wants to outplant during summer or fall, 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 the winter.
3. The large number of plants being produced at today's nurseries means that it is physically impossible to lift, grade, process, and ship plants all at the same time. Storage facilities help to smooth out the lift-pack-ship process.
4. Refrigerated storage is a cultural tool that can be used to control plant physiology and morphology. For example, plants can be harvested at the peak of dormancy in autumn and then the chilling requirement can be met by temperatures in refrigerated storage.

Figure 13.2—*(A) Grading consists of separating "shippable" plants from "culls" based on criteria such as (B) root-collar diameter. (C) Larger nurseries "pull and wrap" their stock and pack it into bags or boxes.* Photos by Thomas D. Landis.

Short-Term Storage for Summer or Fall Outplanting

Often, native plants are simply held in a shadehouse (figure 13.3A) or open compound (figure 13.3B) until they are shipped. Both structures are typically equipped with sprinklers, so irrigation and fertigation are possible. Larger containers are stored in wire racks to keep them upright and to stop roots from growing into the ground (figure 13.3C). To aid in drainage, prevent seedling roots from growing into the soil, and retard weeds, plants can be placed on a layer of pea-sized gravel covered with landscape fabric. Fabric impregnated with copper can also be purchased that chemically prunes roots as they emerge from the bottom of the containers (figure 13.3D).

Overwinter Storage

The importance of properly overwintering stock is often overlooked by novice native plant growers because their emphasis is on growing the plants. Many plants have been damaged and some crops have been completely lost as a result of poorly designed or managed overwinter storage. In northern climates, it is common for native plant nurseries to lose 10 percent or more of their nursery stock during winter, and growers who fail to provide adequate protection may lose half or more of their plants.

Causes of Overwinter Damage

Before we talk about types of storage systems, let us first discuss the main causes of injury to stored plants (table 13.2).

COLD INJURY

Cold injury can develop from a single frost or during an extended period of cold weather. Damage is most common in late autumn or early spring, when plants are entering or coming out of dormancy (figure 13.4A). Cold injury is directly related to seedling dormancy or cold hardiness. Properly hardened shoots of northern native plants can tolerate temperatures to –40 °F (–40 °C) or lower, but cold hardiness and dormancy are lost as winter progresses.

Root systems are injured at much higher temperatures than shoots, so roots need special protection.

ROOTS ARE NOT AS HARDY AS SHOOTS

12 °F (–11 °C) is the lowest temperature that young seedling roots should have to endure.

–20 °F (–29 °C) is the lowest temperature that mature roots can handle, but this critical temperature varies greatly by species.

34 to 41 °F (1 to 5 °C) is an ideal temperature for overwintering newly rooted cuttings.

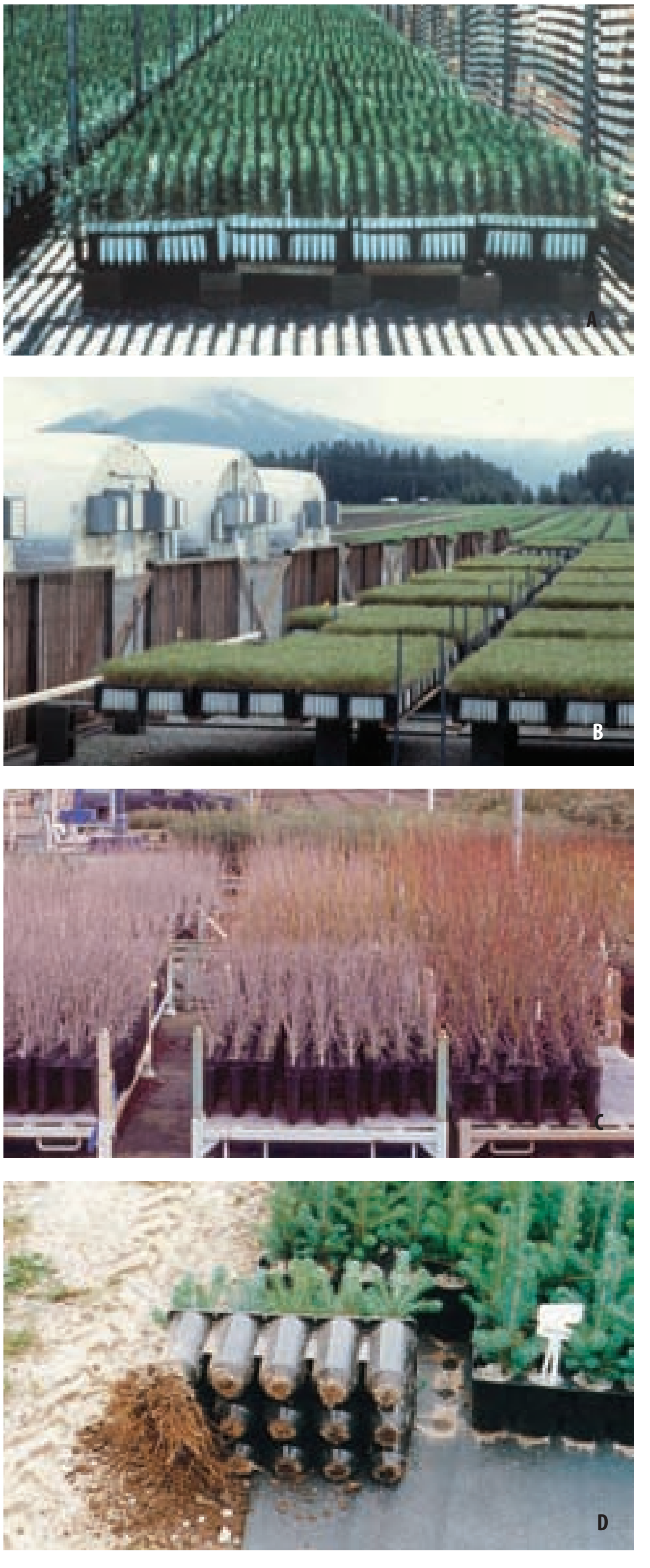


Figure 13.3—*(A) For short-term storage, plants may be held in shadehouses, or (B) open compounds. (C) Large single containers require metal racks to keep them upright. (D) Copper-treated fabrics are ideal for ground storage because they chemically prevent plant roots from growing into the ground.* Photos A–C by Thomas D. Landis, D by Stuewe & Sons, Inc.

Furthermore, mature roots are hardier and will tolerate colder temperatures than will younger, less hardy roots. Rooted cuttings are particularly vulnerable to injury because their roots have not developed protective layers yet. Young roots are typically located on the outer portion of the root plug and are the first to be injured by cold temperatures (figure 13.4B). In areas 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 roots from damaging temperatures during overwinter storage.

DESICCATION

Winter drying is actually desiccation injury and occurs whenever plants are exposed to extreme moisture stress caused by wind and/or direct sunlight (figure 13.4C). Damage is most severe when the growing medium and roots remain frozen for extended periods. Plants can even become desiccated when stored under frost-free refrigeration without proper packaging. Winter drying is not directly related to seedling dormancy or cold hardiness; even the most dormant and hardy stock can be damaged. Plants stored near the perimeter of sheltered storage are most susceptible (figure 13.4D), but any plant can be damaged if its shoot becomes exposed. This type of desiccation can be prevented if plants can be irrigated during the winter storage period, and perimeter insulation is effective.

FROST HEAVING

Repeated freezing and thawing can cause young seedlings or new transplants to be physically lifted out of the growing medium. Frost heaving is much more common in bareroot nurseries but can still occur when small container plants are exposed to freezing and thawing. Mulches are effective in preventing damage.

LOSS OF DORMANCY

This type of injury is most common when container stock is overwintered in greenhouses. Often, periods of clear, sunny weather during the winter warm the greenhouse and can cause plants to lose dormancy. This condition is particularly true of root systems because roots grow whenever temperatures permit. 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 factor keeping them from growing (figure 13.4E). Use white or reflective coverings to reflect sunlight and reduce heat buildup, and ventilate greenhouses frequently.

STORAGE MOLDS

The type of storage conditions will determine the types of disease problems that will 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 13.2). 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 (figure 13.4F). 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.

DESIGNING AND LOCATING A STORAGE FACILITY

The type and design of a storage system depends on the general climate of your nursery location, the characteristics of the nursery stock, and the distance to the outplanting sites. Most people would think that overwintering would be most difficult the farther north or higher in elevation you go, but that is not the case. Nurseries in the Midwest or the Great Plains are the most challenging because of the extreme fluctuations in temperature that occur during winter. The east slope of the Cascade Mountains or Rocky Mountains can be just as challenging because of the number of clear, windy days and temperatures that can fluctuate 40 °F (22 °C) within a 24-hour period.

Some plants are easier to store than others. Native species that tend to overwinter well are those that achieve deep dormancy and can withstand low or fluctuating temperatures. Therefore, storage systems must be matched to the plant species being grown and the local climate. In tropical or semitropical climates, plants never undergo a true dormancy and can be outplanted almost any time of the year. Plants from coastal areas are never exposed to freezing and tend to be less hardy than those from inland areas.

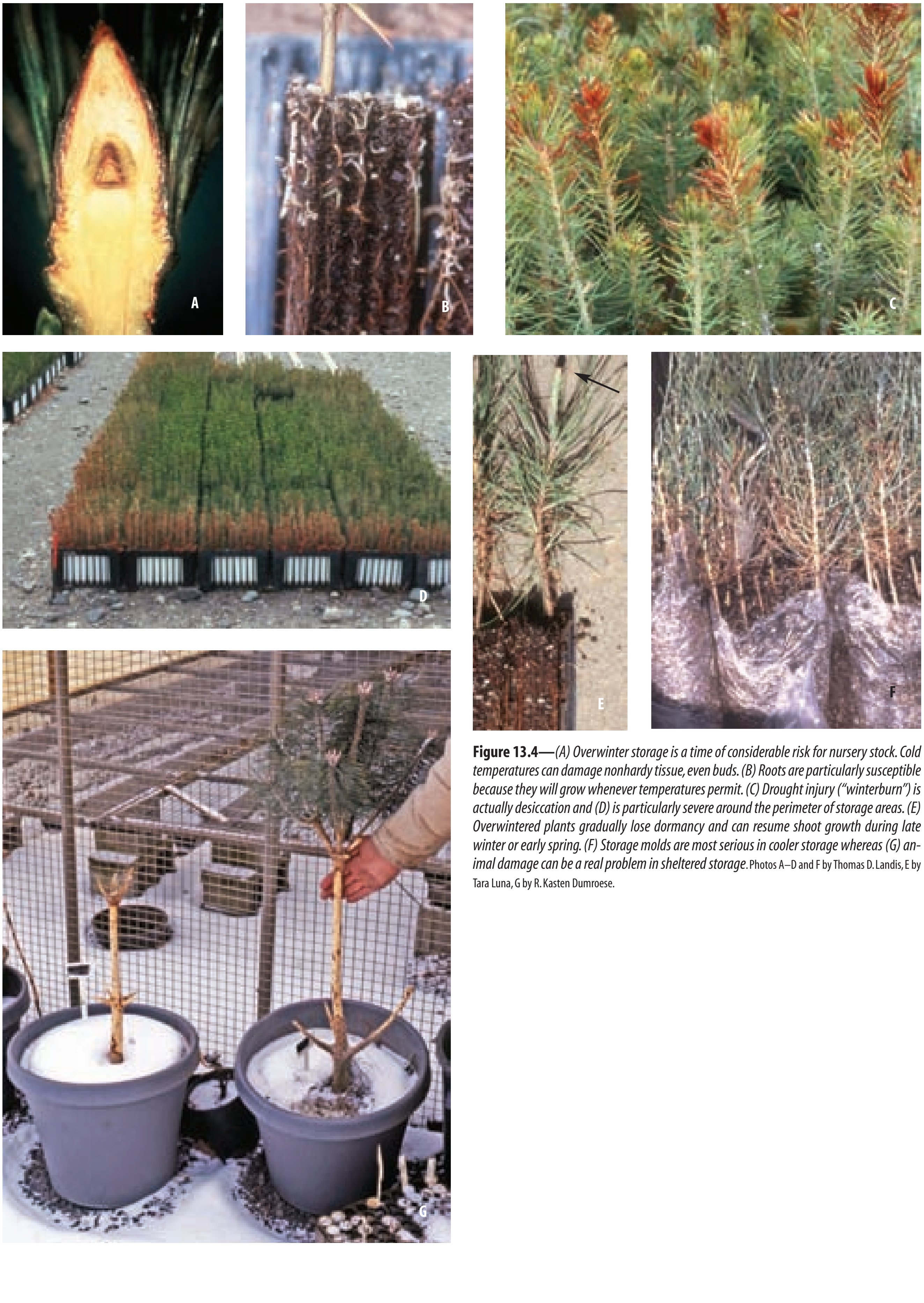


Figure 13.4—*(A) Overwinter storage is a time of considerable risk for nursery stock. Cold temperatures can damage nonhardy tissue, even buds. (B) Roots are particularly susceptible because they will grow whenever temperatures permit. (C) Drought injury ("winterburn") is actually desiccation and (D) is particularly severe around the perimeter of storage areas. (E) Overwintered plants gradually lose dormancy and can resume shoot growth during late winter or early spring. (F) Storage molds are most serious in cooler storage whereas (G) animal damage can be a real problem in sheltered storage.* Photos A–D and F by Thomas D. Landis, E by Tara Luna, G by R. Kasten Dumroese.

Table 13.2—Plants can be injured by several types of stress during overwinter storage

Damage	Cause	Preventative Measure for Each Storage Type: Open	Sheltered	Refrigerated
Cold injury (figures 13.4A and B)	Temperature is below seedling cold hardiness level. (Roots are much more susceptible than shoots.)	Properly harden seedlings to tolerate maximum expected cold temperatures		
Drought injury (winter desiccation) (figures 13.4C and D)	Exposed to intense sunlight or drying wind	Bring media to field capacity before storing		
		Shade plants and protect from wind	Cover stock with moisture-retaining film	Use moisture-retentive packaging
Frost heaving	Repeated freezing and thawing of growing medium	Don't overwinter small plants; insulate containers and apply mulch to tops of containers	Not a problem	Not a problem
Loss of dormancy (figure 13.4E)	Temperatures above 40 °F (4 °C)	Not possible to control	Not possible to control	Maintain cold in-box temperatures.
Storage molds (figure 13.4F)	Temperature is warm; latent infections of *Botrytis*	Prevent injury to seedling tissue, cull damaged plants		
		Keep foliage cool and dry	Remove dead foliage before storing	Use freezer storage if longer than 2 months
Animal damage (figure 13.4G)	Small rodents and even rabbits can girdle stored nursery stock	Exclude larger animals with fencing; use poison bait for rodents	Exclude larger animals with fencing; use poison baits for rodents	Not a problem

All temperate and arctic plants go through an annual cycle of growth and dormancy. In nurseries, plants are cultured into an accelerated period of growth, which must be terminated (during the hardening period) before they can be outplanted. See Chapter 12, *Hardening*, for a complete discussion on this topic. Plants that are fully dormant and 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; 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 the many stresses discussed in the last section.

THE IDEAL OVERWINTER STORAGE SYSTEM DEPENDS ON:

— Location and climate of the nursery.
— Location and climate of outplanting sites.
— Characteristics of the plant species.
— Number of plants to be stored.

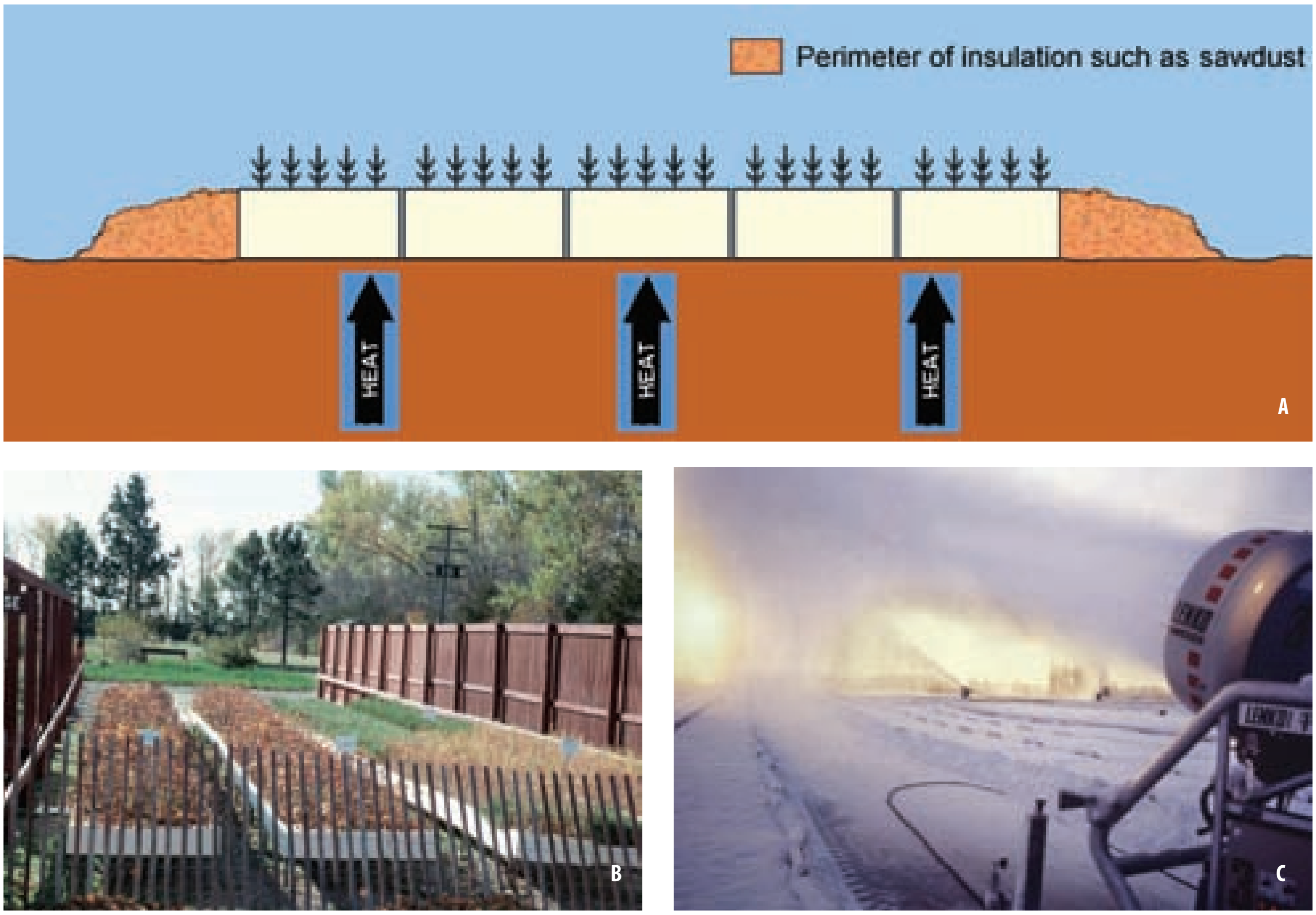


Figure 13.5—*(A) Open storage can be effective when plants are blocked on the ground and surrounded by insulation. (B) Plants should be protected from direct sun and wind by natural or artificial snowfences. (C) Snow is an excellent insulator, and some northern nurseries have augmented natural snowfall with snow-making equipment.* Photos by Thomas D. Landis, illustration by Jim Marin.

Common Systems for Storing Container Plants

The storage system that you select will depend on the species being grown and the severity of winter conditions where the nursery is located. Generally, four systems are used: open storage, tarp storage, storage structures, and refrigerated storage. In many nurseries, more than one overwintering system is used to accommodate the requirements of different native plant species.

Open Storage

In areas with freezing temperatures, open storage is the least expensive but most risky overwintering option. Select an area of the nursery that has some protection from wind and where cold air will drain away. Use gravel and/or drainage tile to promote the free drainage of rain or snowmelt in the spring. Pack all containers together tightly and insulate the perimeter with straw bales or a berm of sawdust. With this perimeter insulation, the roots of stored plants will be protected by heat stored in the ground (figure 13.5A).

Open storage is most successful in forested areas of 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–west oriented bays between vertical snowfence (figure 13.5B). 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 snow-making equipment (figure 13.5C).

Tarp Storage

These are the simplest and least expensive ways to overwinter container stock. In tarp storage, plants are enclosed with a protective covering that is not mechanically supported. Many different coverings

Figure 13.6—*(A) The simplest and least expensive way to store container stock is to bunch them on the ground and cover with a sheet of white plastic. (B) In colder climates, nurseries use Styrofoam™ sheets and sheeting to provide more insulation.* Photo A by Thomas D. Landis, B by Tara Luna.

have been used but the basic principle is the same: to provide a protective, insulating layer over stored plants. Clear plastic should never be used because it transmits sunlight and temperatures within the storage area can reach damaging levels. Because they reflect most sunlight, white or reflective coverings are preferred. Because the tarp materials are lightweight, they need to be secured against wind by burying the edges with concrete blocks, wooden planks, sand, or soil. All tarps are eventually decomposed by direct sunlight, so store them in a dry, dark location (Green and Fuchigami 1985).

Single layer, white, 4-mil copolymer plastic films are the most common type of storage tarp (figures 13.6A and B). White is preferred because it reflects sunlight and keeps temperatures from building up under the covering. Another tarp, Microfoam™ is a breathable, Styrofoam™-like material that is lightweight, reusable, and easily removed and stored. It can be placed directly on plants or supported by a structure. It prevents wide fluctuations in temperature, minimizes heat buildup, and protects roots even if air temperatures drop to 10 °F (–12 °C). Although one layer of Microfoam™ is probably insufficient in harsh climates lacking reliable snow cover, such as those in northern Minnesota and North Dakota (Mathers 2004), it should not be used in conjunction with plastic sheeting because excessive moisture will develop. Rigid sheets of Styrofoam™ can be used to protect plants, too (Whaley and Buse 1994).

Other tarping material includes plastic Bubble Wrap® sheeting, which has better insulation value than regular plastic sheeting and is reported to be cheaper and more durable than Microfoam™ sheets (Barnes 1990), and frost fabrics. Woven and nonwoven landscape fabrics are usually white in color to retard solar heating but allow the infiltration of air and precipitation. Frost fabrics are available in a range of weights and thicknesses providing 4 to 8 °F (2 to 4 °C) of thermal insulation.

In harsh, northern climates without reliable snow cover, some nurseries cover their plants with a "sandwich" of straw or other insulating material between two layers of clear plastic sheeting. The clear plastic and straw create additional heat on clear, frigid days and provide more constant temperatures during the overwintering period when compared with other systems (Mathers 2003). In general, the sandwich covers provide better insulation but cannot be temporarily removed or vented during periods of sunny, warm, winter weather (Iles and others 1993).

TIMING IS CRITICAL

Any tarp storage system is effective only if applied after plants have developed sufficient hardiness and, most important, is removed before plants lose dormancy in the spring.

Storage Structures

COLD FRAMES

A variety of cold frames have been used for overwinter storage. In northern Alberta and Alaska, cold frames constructed of sideboards lined and topped with rigid Styrofoam™ sheets have proven effective (figure 13.7A). During warm periods in the winter or as soon as weather conditions permit in the spring, the top layer of insulation is removed so that plants can be irrigated (figure 13.7B). Cold frames constructed of wooden pallets supported by cement blocks and covered with white plastic polyethylene (poly) sheeting are considered the most effective overwintering system for conifer plants at a nursery in eastern Canada (White 2004).

POLYHUTS AND POLYHOUSES

Polyhuts are simple, inexpensive structures, generally less than 4 ft (1.2 m) high, with a wooden, pipe, or cable frame covered by white plastic sheeting (figure 13.8A) or a "sandwich" of Microfoam™ between two layers of plastic (figure 13.8B). Polyhouses are similar in structure but taller (6 to 7 ft [1.8 to 2.1 m] high) to allow better access. The ends of these structures are opened for cooling during sunny, warm periods during winter (figure 13.8C). Although a single layer of white poly sheeting is adequate protection in milder climates, a double layer of white plastic inflated by a small fan provides better insulation in colder locations. If frigid temperatures occur (0 °F [–18 °C] or colder), however, plants would need additional protection such as a sheet of white poly film or a Microfoam™ blanket (Perry 1990). Some nurseries position a separate plastic sheet within the structure so that it can be temporarily pulled over the plants to provide additional protection during unusually cold conditions. Some growers supply just enough heat in their polyhouses to keep the ambient temperatures around 38 °F (3 °C), an effective technique for a wide variety of native plants in Colorado (Mandel 2004).

Any closed structure needs to be monitored carefully. If possible, orient structures with the longest axis north–south to equalize solar heating, which avoids problems with plants drying out unequally. Ventilation is necessary on warm winter and early spring days (figure 13.8C) and can be as complex as thermostat-activated fans and louvers or as simple as opening end doors. To

CHARACTERISTICS TO CONSIDER IN CHOOSING A STORAGE SYSTEM

— Does your system provide adequate protection to plant roots?
— Does it reduce moisture loss thus avoiding tissue burn?
— Is it easily handled and managed?
— Is it economical?
— Can it be adapted to the growth habit of the plant and size of container stock?

Figure 13.7—*(A) Cold frames of wood and rigid Styrofoam™ sheet insulation are used to overwinter container plants in northern climates. (B) When weather conditions permit, the top layer of insulation is removed so that plants can be irrigated.* Photos by Thomas D. Landis.

prevent desiccation, deflect air movement above the plants toward the roof, where the warmest air will accumulate. Even less-hardy nursery stock, such as newly rooted cuttings, can be overwintered in cold frames provided containers are packed tightly together and perimeter containers and the tops of all containers are insulated.

SHADEHOUSES

Shadehouses are traditional overwintering structures that provide protection from direct sun and wind, and their design will vary with nursery climate and location.

A typical, shadehouse for overwinter storage has shading on both the roof and the sides to protect plants from adverse weather (figure 13.9A), including high winds, intense rains, hail, and heavy snow. Its exact design varies with nursery climate and location. In areas where prolonged cold temperatures are not usual, plants can be overwintered under shadecloth. In wet climates, a waterproof roof is desirable to prevent overwatering by rain and the leaching of nutrients from containers. In areas that receive heavy, wet snowfall, shadehouses must be constructed to bear the load or the covering must be removed to allow the snow to fall onto the crop and insulate it. Shadehouses reduce sunlight by about 30 to 50 percent, thereby reducing seedling temperature. This shade, combined with reduced exposure to wind, can significantly lower transpirational water losses associated with desiccation.

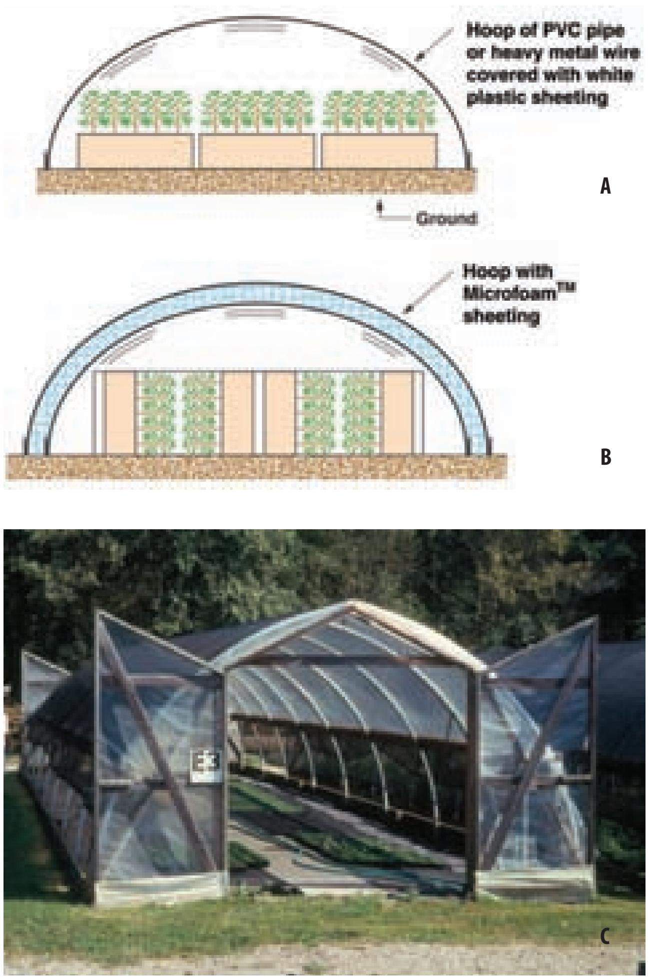


Figure 13.8—*(A) Polyhuts are low structures covered with white plastic or (B) a "sandwich" of poly film and Microfoam™. (C) The ends can be opened for ventilation during warm and sunny winter weather.* Photo by Thomas D. Landis, illustration by Jim Marin.

Figure 13.9—*(A) Shadehouses, such as this one at the Colorado River Indian Tribes nursery in Arizona, provide adequate overwinter protection in warmer climates. (B) When freezing is expected, roots must be protected.* Photos by Thomas D. Landis.

Because it regulates dormancy release, temperature is the most important factor to monitor during overwinter storage.

Sensitive roots can be protected by grouping plants on the ground and surrounding them with an insulating material such as sawdust or Microfoam™ panels (figure 13.9B). Because shadehouses have sides, they protect plants from large animal pests such as deer and rabbits.

GREENHOUSES

Very sensitive plants, such as newly rooted cuttings with tender adventitious roots, can be overwintered in a greenhouse set for minimal heating to keep air temperatures above freezing. It must be emphasized, however, that greenhouses should not be considered for routine overwinter storage because temperatures can increase too much during periods of sunny weather, causing plants to rapidly lose dormancy. In snowy climates, heat must be used to melt heavy, wet snow to avoid structural damage (figure 13.10A). Retractable-roof greenhouses (figure 13.10B) are the best option; roofs can be closed during cold weather, opened on sunny days to allow heat to escape, and opened during snowfall to provide a protective layer to the crop.

Smaller quantities of newly rooted cuttings can be held in hot frames; hot frames are ideal because bottom heat can ensure that soil temperatures remain about 38 °F (3 °C) while shoots remain dormant with exposure to cooler air temperatures. See Chapter 4, *Propagation Environments*, for details on these structures. During warm, sunny days, hot frames must be opened to allow heat to dissipate.

Refrigerated Storage

Refrigerated storage is, by far, the most expensive way to store nursery stock and therefore is practical only for large native plant nurseries. Biologically, however, operational experience at the USDA Forest Service nursery in Coeur d'Alene, Idaho, shows that most native plant species can be stored very effectively under refrigeration.

Figure 13.10—*(A) Fully enclosed greenhouses can be used for overwintering sensitive species but snow removal is necessary in cold climates to prevent damage. (B) Retractable-roof greenhouses are better for overwinter storage because they can be opened to allow snow to cover plants.* Photos by Thomas D. Landis.

PRE-STORAGE CHECKLIST

—Ensure that all plants have been properly hardened and dormant; this can vary considerably among species.
—Cover plants as late in the fall as possible so plants can achieve maximum hardiness.
—Ensure that water drains freely from the ground of the overwintering area.
—Remove any remaining leaves from deciduous species.
—Cut leaves back to crown level on grasses and herbaceous perennials.
—Consolidate and pack all containers together tightly.
—Irrigate nursery stock thoroughly 1 to 2 days before covering.
—Do not cover wet plants, wait until the tops are dry before covering.
—Lay large container plants on their sides, packing containers together as tightly as possible without damaging tops.

Table 13.3—A comparison of types of refrigerated storage

Type	In-box Temperature	Length of Storage	Type of Packaging Around Plants
Cooler	33 to 36 °F (1– 2 °C)	1 – 2 months	Kraft-poly bags Cardboard boxes with thin plastics liners
Freezer	30 to 25 °F (–2 to –4°C)	3 – 6 months	Boxes with moisture retentive liner

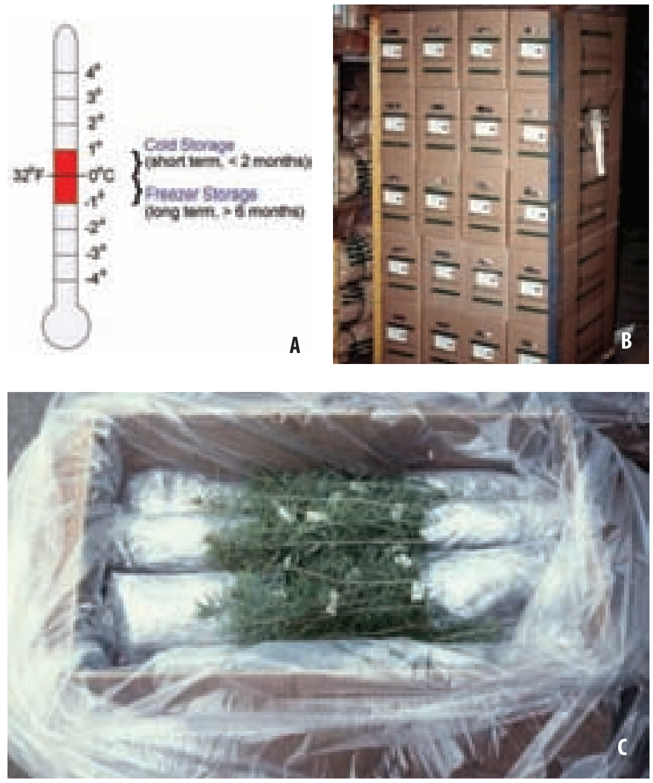


Figure 13.11—*(A) Although only a few degrees of temperature differentiate cooler and freezer storage, the duration of storage is very different. (B) Packaging is critical for freezer storage and most nurseries use waxed boxes that (C) are lined with a plastic bag to retard moisture loss.* Photos by Thomas D. Landis, illustration by Jim Marin.

The two types of refrigerated storage used in native plant nurseries are cooler and freezer storage, which are differentiated by their temperatures (figure 13.11A) and by type of packaging around the plants (table 13.3).

Refrigerated storage is effective for holding nursery stock because the lower temperatures suspend plant metabolic activity and conserve stored carbohydrates. The rule of thumb is to use cooler storage when plants are stored less than 3 months (or when shipments of plants occur throughout the storage period) and freezer storage when the duration is longer than 3 months because it significantly reduces 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 (figure 13.4F).

The type of packaging for refrigerated storage is very important. Most nurseries use special wax-impregnated boxes because they withstand moist conditions and are easy to handle and stack (figure 13.11B). Because long-term refrigeration withdraws moisture, boxes must be lined with a plastic liner (figure 13.11C).

Most conifers do well in freezer storage, while broadleaved trees and shrubs do better in cooler storage. Considerable variation exists among species, however, and there is no substitute for practical experience. Some species, such as black walnut and eastern dogwood, have serious problems with rots in refrigerated storage. Other dry desert species that retain their leaves all year, such as sagebrush and bitterbrush, are very susceptible to *Botrytis* and should not be stored under cooler storage. Very little information, unfortunately, has been published about the refrigerated storage of other native plants.

MONITORING STOCK QUALITY IN STORAGE

During overwinter storage, plants can be visualized as being in a state of "suspended animation"—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. It is important to measure temperature at the levels of the plants and especially around the roots. Electronic thermometers with long probes are very useful for monitoring temperature in storage containers (figure 13.12A). Small and inexpensive temperature monitoring devices can monitor temperature over time, and the data can be downloaded to a computer (figure 13.12B). Any thermometer must be calibrated annually to make sure it is accurate. To calibrate, place the temperature probe in a mixture of ice and water; the temperature should read exactly 32 °F (0 °C) (figure 13.12C).

After temperature, the next most critical factor to monitor is moisture because even hardy, dormant

Figure 13.12—*(A) Temperature can be monitored with long-stemmed electronic thermometers. (B) Small devices such as 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-ice mixture to make sure it is accurate.* Photos A and C by Thomas D. Landis, B by David Steinfeld.

plants can dry out during overwinter storage. Although desiccation is more of a concern with evergreen species as they will transpire whenever exposed to heat and light, deciduous species can be damaged, too. Therefore, check plants routinely during the storage period and irrigate if necessary.

Some species, such as taprooted herbaceous dryland perennials, species with bulbs or fleshy roots, and some species of grasses, are especially susceptible to winter mortality when moisture is excessive (Iles and others 1993). The best storage for these types of species is a waterproof structure that has good drainage. Removing leaves around the bud crowns prior to overwinter storage is also helpful.

Rodent damage is a major cause of loss because most overwintering systems are a perfect nesting site for rodents (figure 13.4G). Rodent damage is usually worse during years of deep snow accumulation because rodents are less able to forage for food and are protected by the snow from predators.

SPECIAL LIFTING WINDOWS

Just as with plants destined for overwinter storage, plants harvested for **summer outplanting** should undergo some hardening to prepare them for outplanting. Often, stock for summer planting is moved from the greenhouse to an outdoor area and the amount and frequency of fertigation is reduced for a period of at least a month before the plants are to be outplanted. Because these plants will still be actively growing, are relatively succulent, and have minimal or no cold hardiness, they should be held only in sheltered storage or should be cooler stored for a few days. The plants can be shipped directly to the outplanting site in their containers, or they can be graded and packed as described previously. If the latter, the plants must be outplanted promptly to avoid problems with desiccation and overheating.

Plants for **fall outplanting** usually have received a moderate amount of cold hardening but are not fully dormant when harvested. Nurseries either can ship plants in the container or pack them as for summer outplanting. If refrigerated storage is available at the nursery or on the outplanting site, only cooler storage is recommended because freezer storage may damage nonhardy tissue. The storage duration should be limited to a few days or weeks.

For either summer or fall outplanting, nursery location should be considered. Nurseries located close to the project area may be able to lift plants and deliver them quickly to the outplant site with little or no storage ("hot plant"). As the distance increases, however, some type of cooler storage facility is needed to preserve plant quality.

SHIPPING CONTAINER STOCK

Regardless of when the lifting window occurs, nursery plants have optimum quality when they are in the nursery and are most vulnerable when they are shipped to the outplanting site. Therefore, it is important to be particularly cautious when handling nursery stock to make sure that it has the best chance for survival and growth. This is particularly true of plants not stored under refrigeration because they will be less dormant and hardy. The true impact of careless handling is not immediately apparent; it causes a degree of sublethal injury that will be observed only as a decrease in survival and growth after outplanting. Because all types of abuse or exposure are cumulative, think of nursery plant quality as a checking account. Plants are at 100 percent of quality when they are at the nursery, and all stresses are withdrawals from the account (figure 13.13). Note that it is impossible to make a deposit; nothing can be done to increase plant quality after a plant leaves the nursery.

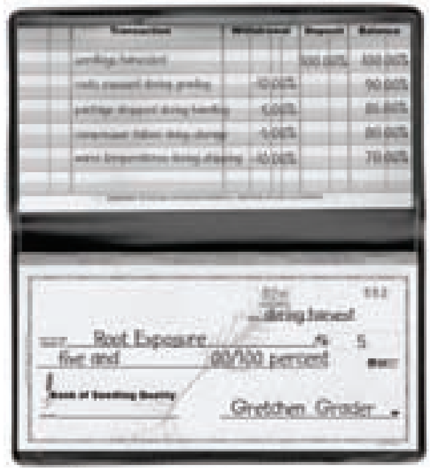
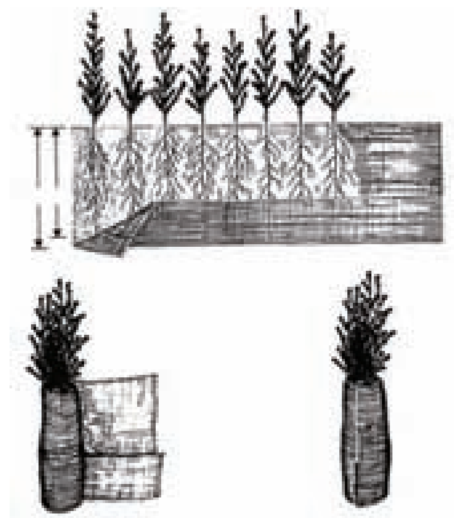


Figure 13.13—*It is useful to think of nursery plant quality as a checking account; all types of abuse or stress are cumulative and can only decrease quality.* Illustration by Jim Marin.

Minimizing Exposure

Nursery plants should be handled with care and protected from direct exposure to sun and wind. Research has shown that desiccation is more of a concern than warm temperatures during shipping. A comprehensive evaluation of the various types of stresses affecting plants during storage, handling, and outplanting revealed that desiccation of the root system was the most damaging factor and that direct sunlight and high temperatures were significant only as they increased moisture stress. Special tarps are available that reflect sunlight and insulate nursery plants during the shipping process (figure 13.14A). Never place nonreflective tarps directly on seedling boxes; this practice will increase the temperature more than if the sun shines directly on them. If plants have to be carried long distances, some nurseries "jellyroll" plants to protect roots from desiccation. The process consists of aligning the plants with the roots folded in a wet cloth, rolling them into a bundle, and securing the bundle (figure 13.14B).

A



B

Figure 13.14—*(A) Special tarps protect nursery plants from direct exposure to sun and wind during shipping. (B) Jellyrolling has been used when plants have to be transported for long distances.* Photo by Thomas D. Landis, illustration by Jim Marin.

Physical Shock

Nursery stock should always be handled with care during shipping. Although research has shown that plants are relatively tolerant of vibration and dropping, all types of mishandling are cumulative and should be avoided. Placing container plants in cardboard boxes provides some protection and white boxes are best (figure 13.15A). During shipping, plants should be stored under an insulating tarp or in a white, insulated truck box. For large shipments, truck boxes can be equipped with racks to protect the plants (figure 13.15B).

CONCLUSIONS AND RECOMMENDATIONS

The successful overwintering of container plants is one of the most challenging and important aspects of nursery management. To ensure maximum winter survival of container plants, growers should provide adequate nutrition during the growing season, properly harden stock during late summer and autumn, determine root hardiness by species, and provide the degree of protection needed by the species or stock type. Many types of overwintering systems can be employed, and, depending on location, climate, and the species grown, more than one system may need to be used.

Determining when it is safe to harvest plants so they maintain a high level of quality throughout the storage period is one of the most challenging parts of nursery management. Nursery managers must use a storage facility that compliments the condition of plants at harvest time and maintains their peak physiological condition until outplanted. Clients should work as a team with their nursery to maintain stock quality. The key concept to remember is that all stresses are both damaging and cumulative and that seedling quality cannot be improved after harvest.

Figure 13.15—*(A) Placing container stock in boxes help protect them from physical shock and (B) they should be handled carefully during shipping.* Photos by Thomas D. Landis.

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APPENDIX 13.A. PLANTS MENTIONED IN THIS CHAPTER

bitterbrush, *Purshia* species
black walnut, *Juglans nigra*
cedars, *Thuja* species
eastern dogwood, *Cornus florida*
junipers, *Juniperus* species
sagebrush, *Artemisia* species
sedges, *Carex* species