Chapter 22

Nursery storage to Planting Hole: A Seedling's Hazardous Journey

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Abstract

The nursery environment can be heavily manipulated by nursery personnel, but the field environment into which seedlings are outplanted is less controllable and more diverse. Therefore, nursery manager and customer must work hand in hand to promote careful seedling processing and handling to ensure plantation success. Once lifted, the extremely vulnerable seedlings must be protected from temperatures above 2°C, freezing, relative humidities below 90%, plant moisture stress above 5 bars, and rough handling. Any damage incurred has a cumulative effect on seedling vigor. Seedlings must be shipped in containers that maintain proper environmental conditions and protect them from physical abuse; kraft/polyethylene bags are the most satisfactory container currently in use. Refrigerated vans with racks that allow air to circulate and heat to dissipate are the most dependable, trouble-free shipping vehicle. Once in the customer's hands, seedlings should be stored in refrigerated facilities for best results, although snow caches can provide excellent storage; mechanical refrigeration units can be either commercial or customer owned, portable or permanent. Planting-site storage requires coolers or tarps to protect seedlings from wind and sun. Planters must handle seedlings with extreme care to avoid injury and potential plantation failure. Nursery managers and customers must maintain close communications at all times to assure that substandard seedling performance is accurately diagnosed so that proper corrective measures can be taken.

22.1 Introduction

The nursery manager's responsibility in the reforestation of cutover timber lands does not end with the production and on-site storage of planting stock. Nursery environment, cultural practices, and seedling processing influence stock performance after planting just as surely as shipping, handling, and planting practices of nursery customers do.

This chapter presents a customer's view of the nursery manager's share of responsibility for plantation success and suggests ways that nursery managers and their customers can work together to promote mutual trust and understanding. It reinforces points already made in other chapters of this *Manual* concerning the microenvironments suitable for young dormant trees and advises nursery managers on points to monitor when visiting customer plantations. The points emphasized apply whether nursery managers and customers are federal, private, or a combination of these.

22.2 The Nursery Environment

The previous chapters in this *Manual* deal almost exclusively with the nursery environment—from nursery-site selection before seed is ever sown (see chapter 2, this volume) to cold storage of trees at the very end of the production process (see chapter 21). Soil structure and fertility can be altered considerably with organic matter and chemical fertilizers (see chapters 6 through 10). Climate can be manipulated by shading devices and watering strategies to protect seedlings from

In Duryea. Mary L., and Thomas D. Landis (eds.). 1984. Forest Nursery Manual: Production of Bareroot Seedlings. Martinus Nijhoff/Dr W. Junk Publishers. The Hague/Boston/Lancaster, for Forest Research Laboratory, Oregon State University. Corvallis. 386 p.

both heat and cold (see chapter 12). Although absolute control of the nursery environment is not possible, a high degree of uniformity and regulation is essential for producing high-quality seedlings. The American Heritage Dictionary includes among its definitions of "nurse" the phrase ". . . to take special care of; foster . . . ." That is what should happen in a forest-tree nursery.

22.3 The Field Environment

By contrast, the physical environment into which seedlings must be planted is less controllable and more diverse than that of the nursery. Seedlings must be able to cope with drought, heat, cold, vegetative competition, and animals—for the most part without assistance from irrigation systems and other artificial means of protection. Seedlings grown in an average-size federal nursery may be destined for 10 National Forests. Whereas one individual, the nursery manager, has been solely responsible for them in the nursery, the seedlings may now be distributed to as many as 40 or 50 National Forest Districts with an equal number of individuals assuming responsibility for their care. The customer range of most private nurseries is even larger. The sheer size of the program assures many opportunities for problems.

22.4 The Seedling's Priorities

The seedling requires rigid control of temperature, moisture, and physical handling at all times during shipping, field storage, and planting. These needs have evolved over literally millions of years and cannot be changed. While separated from the soil, the seedling is in a hostile environment—like a man in space or a fish out of water—and is must vulnerable at this time because adequate protection is difficult to provide.

Compliance from all persons involved with strict handling standards cannot be overemphasized. Other priorities must give way when they begin to infringe upon the seedling's needs. For instance, if truck loads of trees arrive from the nursery late in the day, they must be placed into local storage immediately rather than the next day. At no time should trees be left on trucks over a weekend.

From lifting to outplanting, seedlings must go through 18 to 20 steps during which failure to control temperature and moisture or physical abuse can occur. Each instance of substandard treatment at any point in the production and handling sequence—exposure to high temperature, low humidity, or rough handling—accumulates to the detriment of the seedling [17]. Seedlings in transit or storage have no opportunity to recover from one instance of substandard handling before another occurs.

Although one or two minor violations of seedling priorities may. not be critical, several together will almost surely cause some degree of irreversible damage. For instance, seedlings may tolerate an extra hour or two in the packing shed, a short trip in an open truck, or brief root exposure by careless planters, but all of these occurrences combined may result in physiological deterioration. Though outplanting survival has customarily been the measure of seedling quality and performance, growth reduction due to poor handling is a more serious consequence [1, 19]. It is therefore extremely important that all seedling handlers be aware of seedling priorities and of the need for their rigid observance.

22.5 Shipping Seedlings from the Nursery

The following discussion assumes that seedlings have been lifted while dormant during very late fall or winter for spring planting. Seedlings lifted for early fall planting will probably not be hardened off or fully dormant, so special shipping and handling procedures must be followed. Field foresters must plan regeneration so that trees can be lifted for spring planting while dormant (see chapters 14, 21, and 23, this volume).

During shipping and subsequent field storage, the seedling's immediate environment (inside packages) must be maintained at high relative humidity and low temperature. The standards here are the same as those which must be maintained in nursery storage. Humidity must be in the 90 to 95% range to assure that plants do not become desiccated [11]. However, free moisture must be avoided in seedling packages or the probability of storage-mold growth will be greatly increased [17]. Temperature must be in the 1 to 2°C (33 to 35°F) range to assure a low level of physiological activity and maintenance of dormancy [14]. Seedlings must not be frozen accidentally because cellular damage may result.

Fifty-two percent of seedling producers responding to the OSU Nursery Survey (see chapter 1, this volume) maintain seedling temperatures in transit as follows:

Temperature, °C (°F)	Respondents, %
1-2 (33-35)	14
2-3 (35-37)	24
3-4 (37-40)	14

Although physiological activity may not actually begin until temperatures reach 5°C (41°F) [14], it is extremely risky to permit seedling temperatures to rise that high. If seedlings begin growth in storage, they produce more heat, which induces more growth, which produces more heat, and so on. Once begun, this progression is difficult to reverse. Both shipping containers and vehicles are critical to maintaining the proper environment within packages.

22.5.1 Containers

Shipping packages must protect seedlings from desiccation by maintaining high relative humidity and from physical damage by shielding them from crushing pressure and hard blows. A moisture-holding medium such as sphagnum moss may be included in the shipping container, depending on either the policy of the nursery or the wishes of the customer. Shipping packages must serve both the nursery manager and field forester adequately or they are not acceptable. Close coordination between seedling producers and customers will assure a container that is acceptable to each and that adequately protects the trees.

The OSU Nursery Survey revealed the following proportionate use of packing containers and moisture-retaining media:

Container type	Respondents, %	Medium type	Respondents, %
"Poly" bags	90	None	53
Waxed boxes	43	Sphagnum moss	33
Bales	5	Shingle toe	9
		Peat moss	5

22.5.1.1 Bales

Open-ended bales are the least desirable containers for shipping and long-term storage because seedling tops are exposed to the atmosphere, permitting moisture loss and physical damage (stem breakage and loss of terminal buds). Their one advantage over closed boxes or bags is that seedlings can easily be rewetted if they become dry. Nursery customers who cannot control planting schedules or field-storage duration because of unpredictable planting-site weather should not specify open-ended bales.

22.5.1.2 Waxed boxes

Rigid, waxed cardboard boxes protect seedlings from physical damage and can be well sealed against moisture loss if a plastic liner is used. They are difficult to seal, however, without a plastic liner. A moisture-holding medium is not effective over long storage periods if boxes are not sealed, and rewetting is difficult and time consuming because each box must be opened to do the job. In their favor, boxes are easy to stack and use storage space efficiently. However, closely stacked boxes inhibit heat transfer and can lead to heat buildup within boxes. Special care must be taken in stacking if boxes are used (see also chapter 21, this volume).

22.5.1.3 "Poly" bags

Kraft/polyethylene, or "poly," bags appear to be the most popular and satisfactory storage and shipping container currently in use. Properly sealed bags retain moisture without a moisture-holding medium around roots and protect seedlings from physical damage if handled with normal care; they can keep seedlings moist for storage up to 3 months [4]. Bags are commonly sewn shut or banded by a banding machine with plastic strips (Fig. 1). However, care must be exercised to avoid packing bags so tightly with trees or so close together on stacking racks that heat generated by live seedlings cannot be properly dissipated [14, 17].

Figure 1. Nursery worker closes a "poly" storage bag, leaving room within for air circulation and heat transfer.

22.5.2 Vehicles

Seedlings are quite vulnerable during shipping. Shipping vehicles which contain seedling racks and which can maintain storage packages at temperatures near freezing [11] should always be used.

Temperature and moisture stress within storage packages must not be permitted to increase during shipping. Rising temperature stimulates physiological activity (respiration) in seedlings, which reduces carbohydrate reserves and produces more heat. Seedlings which become active during shipping will be most likely to mold during subsequent storage and continue to lose stored food reserves [17].

The OSU Nursery Survey revealed the following proportionate use of refrigerated vans and transit times:

Refrigerated vans			
Production shipped. %	Respondents, %	Transit time, hr	Respondents, %
0-49	33	2-4	66
50-79	14	5-8	5
80-100	53	9-12	24
		48 or more	5

22.5.2.1 Open trucks

Open trucks or stock trailers are not adequate shipping vehicles. Cloth or other flexible covers alone, including space blankets, cannot protect seedlings adequately from sun and wind during the long trips frequently required to reach customer-owned storage. Seedlings also are subject to freeze injury in such vehicles. If open vehicles must be used, shipping containers should be securely covered with both a damp tarp and a radiation shield such as a space blanket.

22.5.2.2 Insulated vans

Insulated truck or trailer boxes with racks (Fig. 2a), though not the preferred vehicle, are adequate for short trips if the canopy interior is cold at the start and if temperature inside storage packages does. not increase. But insulated vans may not be acceptable for long trips (6 to 8 hours or longer) on warm

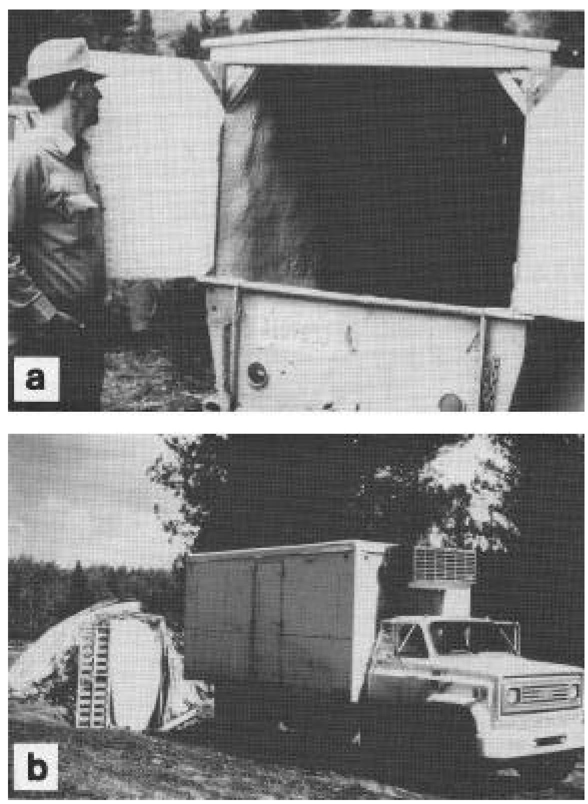

Figure 2. Seedlings may be hauled (a) to planting sites in insulated trailers or (b) from nurseries to local long-term storage in refrigerated vans.

days or nights. If unavoidable and unpredictable delays occur in geographically isolated areas, the probability of seedling damage is great. Again, seedlings can easily freeze in such vehicles, though it would take longer than in rigs with less protection. Insulation of the truck bed is extremely important because the muffler is a primary heat source; an insulated canopy will trap muffler heat if it is not excluded by an insulated bed.

22.5.2.3 Refrigerated vans

A refrigerated van with racks (Fig. 2b) is the most dependable, trouble-free method of shipping seedlings from the nursery [6]. A refrigeration unit with both electric and liquid fuel capacity is probably best because it can operate at any time and place. Therefore, delays enroute usually are not critical.

Nurseries or customers need not own refrigerated vans because reliable commercial units are available on contract. Such haulers handle meat and seafood and can maintain a desired temperature indefinitely. During 1983, commercial refrigeration vans could be hired for $2.l0/loaded mile—or about 1 cent/1,000 seedlings/mile; 200,000 seedlings (approximately one 40-foot van load) could be shipped 100 miles for $210 [pers. commun., 16].

22.6 Monitoring Storage Conditions off the Nursery Site

22.6.1 Ambient temperature and relative humidity

As mentioned earlier, temperature should be held between 1 and 2°C (33 and 35°F) and humidity between 90 and 95% within seedling packages so that seedlings do not break dormancy or become desiccated.

Probe thermometers are best for monitoring temperature within storage containers because they can be used without opening boxes or bags (Fig. 3). However, any holes created in containers by probe thermometers must be taped shut to avoid moisture loss. Thermometers must be carefully calibrated so their accuracy is known; then temperatures should be taken and recorded when seedlings leave nursery storage and again when they enter customer storage.

22.6.2 Within-package monitoring

The critical area for seedling environment is within storage packages, not in the ambient spaces of tree coolers (see 22.7.2). Coolers with ambient temperatures of -1 to 0°C (30 to 32°F)

Figure 3. Monitoring within-package temperature with a probe thermometer.

can be expected to maintain seedling packages at 1 to 2°C (33 to 35°F). Even though cooler spaces may be -1°C (30°F), within-package temperatures as high as 4°C (39°F) have been measured when inadequate racking systems or closely stacked boxes have prevented air circulation. Root-mass temperatures 8°C (14°F) above ambient have been reported under conditions of poor air circulation [21].

The OSU Nursery Survey revealed that 95% of the nurseries questioned do some kind of within-package monitoring:

Condition monitored	Respondents, %
Temperature	90
Mold	52
Plant moisture stress	38
Root condition	24

Customers should also monitor conditions within packages to reduce the number of unknowns when attempting to analyze plantation failure.

22.6.3 Alarm systems

Alarm systems are essential on tree coolers to warn of refrigeration breakdowns. Flashing lights, sirens, or bells are usually installed but may not be adequate if coolers are in remote areas, as many U.S.D.A. Forest Service coolers are. A dialer programmed to ring a responsible person's telephone should also be installed where no one will be close to hear bells or sirens or see flashing lights on cooler boxes. Damaging temperatures can occur in full coolers in a matter of hours if breakdowns are not reported immediately.

For example, a single cooler containing 5,000 ft^3 of storage space can frequently hold up to 300,000 or more seedlings worth, let's say, $30.000. At 500 trees/acre, these seedlings may be used to plant 600 acres. If trees are damaged by inadequate refrigeration, the entire 600 acres may require replanting at a cost of $100/acre—or $60,000 for the planting contract alone. Overhead and contract administration could add another $100/acre, bringing total losses to $150,000. This is a worst-case example on an acre basis (all 600 acres failed), but probably not on a cost basis because these cost estimates are conservative and will almost surely inflate in the future.

22.6.4 Plant moisture stress

The pressure chamber technique [20] is best for monitoring plant moisture stress, or PMS ([5]; see also chapters 12 and 23, this volume). If a relatively dry atmosphere exists, creating a transpirational demand in the absence of a water supply to the roots, atmospheric pull creates tension in the seedling water columns. The chamber measures the pressure necessary to reduce this tension; a high instrument reading means high moisture stress in the seedling. The pressure chamber can be used to determine moisture stress in established as well as stored seedlings.

Stresses above 12 atmospheres (atm)[1] at lifting time are detrimental to seedling survival after outplanting [8]. This, therefore, can be interpreted as a maximum level. A 5-atm PMS has been recommended as a maximum during processing [2] and for seedlings in storage bags; this PMS level is not difficult to maintain and gives an acceptable margin of safety. Stresses higher than 5 atm indicate a problem requiring immediate correction. Humidities of 90 to 95% in shipping containers should be adequate to maintain storage PMS below 5 atm.

The J-14 hydraulic press is not considered a satisfactory tool for monitoring PMS at this time [5, 13]. Whereas the pressure chamber uses intact dead plant cells to reveal PMS,

[1] 1 atm = 14.7 psi = 1 bar.

the J-14 press crushes both live and dead cells. Pressure chamber use is based on proven physical theory [20]; use of the J-14 press is not. To date, tests have revealed little correlation between pressure chamber and J-14 press readings of PMS (see also chapter 23, this volume).

Nursery managers should take an active part in educating seedling customers on temperature and moisture stress and on the best equipment for monitoring PMS.

22.7 Customer Facilities

If nursery customers pick up or receive seedlings more than 1 or 2 days before planting dates, they must have storage capable of maintaining the temperature and humidity conditions previously identified. If the customer does not own such storage, commercial facilities are available in most cities, or refrigerated vans used to haul frozen foods over the highway can be rented and positioned near planting sites. Even if the customer intends to plant trees immediately on delivery, arrangements should be made to store seedlings under controlled conditions. For instance, if planting begins immediately but requires a week for completion, those trees planted after the second day probably will suffer without controlled storage. Furthermore, planting schedules frequently do not proceed as planned.

22.7.1 Nonrefrigerated storage

Most types of nonrefrigerated storage in which environmental conditions are not controlled (such as unheated buildings or root cellars) do not provide adequate protection for dormant seedlings. Snow caches are an exception to this rule.

22.7.1.1 Unheated buildings

In the past, seedlings were planted as they came from the nursery or were stored in shady areas or well-ventilated, unheated buildings. During the winter, these methods may have been adequate for periods up to a week. Over longer periods, however, normal daily temperature fluctuations above or below freezing can cause irreversible damage.

22.7.1.2 Root cellars

Root cellars, also used as temporary storage, will protect seedlings from freezing but are not cold enough to maintain dormancy or retard mold growth. Although root-cellar temperatures do not fluctuate widely, dampness at temperatures in the 10 to 13°C (50 to 55°F) range creates an excellent environment for mold growth, which presents a serious threat to the quality of stored seedlings [12].

22.7.1.3 Snow caches

Properly designed and constructed snow caches (Fig. 4) can provide excellent storage conditions for tree seedlings [7]. Temperature fluctuations are almost absent; the level will stay near 0°C (32°F). Relative humidity will be near 100%. Seedlings remain dormant, and mold growth is negligible.

To be practical, snow caches should be planned only where snow can naturally be expected. However, some U.S.D.A. Forest Service units have built them using snow machines like those used by ski-resort concessionaires.

22.7.2 Refrigerated storage

Mechanical refrigeration is probably the best choice for large planting programs. Storage need not be customer owned, and either portable or permanent units can be used.

22.7.2.1 Portable units

Portable units may be inadequate for removing heat due to inferior air circulation and unsatisfactory for maintaining proper relative humidity. Though controlling humidity is less critical for short-term storage of sealed packages, low humidity can still be damaging, and the potential for such damage increases with increased storage time. Frequently, because storage time cannot be accurately predicted, methods of humidity control become critical.

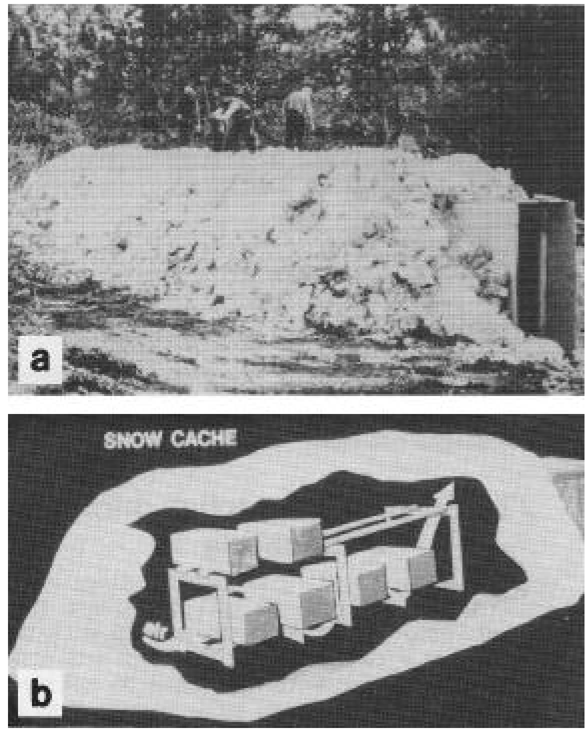

Figure 4. (a) A snow cache used for long-term field storage; (b) racks in snow caches (as in shipping vehicles) permit the circulation of air necessary for heat transfer.

If portable units must be used, wet burlap on the floor or draped over storage racks is an acceptable way to maintain adequate humidity. Care must be exercised to keep seedling storage bags dry, however, because bags are more vulnerable to handling damage when wet. Free moisture in contact with storage containers also must be avoided because it is an invitation to mold problems.

22.7.2.2 Permanent units

Permanent storage units (Fig. 5) are best for carefully controlling temperature and humidity during long storage periods. Seedlings which are lifted during late winter but which cannot be planted until spring need the best storage that can be provided. Frequently, nurseries do not have enough cooler space in which to store their entire crop until snow leaves planting sites. If this is the case, other long-term facilities must be sought. For example, excellent equipment normally used to store fruit in Oregon and Washington may be rented to store seedlings in the off-season for fruit.

22.7.3 Frozen storage

For the time span most seedling customers need storage (1 to 3 months), frozen storage should not be necessary, though it may be beneficial for longer times (3 to 5 months). But as storage length increases, the probability of equipment failure increases. While this is also true of conventional nonfreezing storage, the consequences of equipment failure in conventional storage are less detrimental and easier to handle.

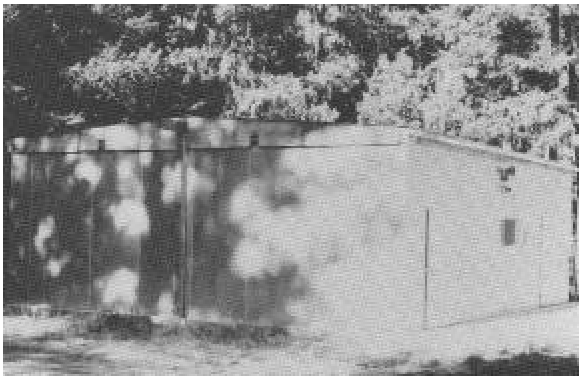

Figure 5. A permanent U.S.D.A. Forest Service tree cooler for storing seedlings at field units.

22.8 Seedling Protection during Outplanting

Seedlings remain in their original shipping package, where they are relatively easy to protect, until planting time. They must then be removed from the package and exposed to the atmosphere. Just a few seconds' exposure to a desiccating atmosphere can cause irreversible root damage because seedling root tips have no protective cuticle covering them as needles do. At this point, it is not as important to keep seedlings cool as it is to keep them wet. However, because not all seedlings taken to the field on a given day maybe planted that day, they must also be kept cool.

Transportation from customer storage to the planting site should be either in refrigerated vans, which can be parked at the site, or in insulated truck canopies.

22.8.1 Planting-site storage

Planting-site storage is usually for 1 day or less. If 2 days are required, the seedlings should be returned to refrigerated storage overnight, mostly for protection from freezing, unless they are kept in a portable insulated or refrigerated unit at the planting site. Packages must always be kept in the shade regardless of storage method.

22.8.1.1 Desert cooler

The desert cooler technique (heat loss through evaporation) is satisfactory for keeping seedlings cool if evaporation surfaces can be kept moist. Wet burlap is a good moisture-holding medium, and wet storage bags at this point in the planting process are not a problem. Bags direct from refrigeration can be kept well below 4°C (39°F) in shade all day even when ambient temperatures approach 16 to 18°C (61 to 64°F).

22.8.1.2 Tarps

Reflective covers such as space blankets or the Seedling Heat Shield® do an excellent job of maintaining a cool atmosphere and shielding seedling packages from drying winds and radiation (Fig. 6). Such tarps reflect sunlight and heat outward and also trap the residual cold of refrigeration. Canvas tarps are not acceptable seedling covers because they tend to transmit heat inward as well as permit cold to escape [9].

22.8.1.3 Acclimatization

Acclimatization was developed in conjunction with "jelly rolling" (see 22.8.2.3) to permit seedlings to become gradually accustomed to planting-site climate. Seedlings are stored overnight at the planting site, usually in a tent, to reduce the shock of going directly from storage temperature to warmer planting-site temperatures. Though this sounds like a good idea and though planting systems using the acclimatization principle in conjunction with "jelly rolling" are quite successful, no studies are known which demonstrate the physiological desirability of acclimatization [pers. commun., 15]. Dormant seedlings appear not to be damaged by fairly wide fluctuations in normal temperature, though actively growing seedlings would be damaged by freezing [4]. If benefits truly do accrue from acclimatization, they are probably associated with the moisture-rich atmosphere in which seedlings are held. "Jelly rolling" may be advantageous where even a slight increase in moisture within the tree could benefit planting situations.

22.8.2 Planter handling

Careless handling and planting can undermine the most flawless stock production, shipping, and storage practices [3, 10]. Of those involved, planters probably have the smallest stake in long-term performance of planted stock. Therefore, those charged with the reforestation responsibility must help planters learn proper care and handling procedures for seedlings before and during planting.

22.8.2.1 "Bagging up"

The highest probability of damaging root exposure occurs when planters fill planting bags with trees. This operation must be done quickly. Planters counting trees must do so with trees in the packing bag, their roots immersed in a bucket of water, or in a tent shielded from the wind—not on the tailgate of a pickup. If storage containers are not completely emptied of seedlings, care must be taken to close them after bagging up.

22.8.2.2 Root dips

Dipping roots in aqueous solutions of various moistureretaining products or in plain water immediately before trees are bagged for planting helps protect roots from desiccation during the short time they are exposed during planting [18]. Ground peat moss, horticultural-grade vermiculite [6], or a mixture of the two is frequently used. Other moisture-holding products such as Terra Sorb® also have been tried, though experience with them is limited.

22.8.2.3 "Jelly rolling"

The term "jelly roll" has been used to describe a seedling protection method developed by the U.S.D.A. Forest Service in Utah. Seedlings are rolled into a water-saturated burlap

Figure 6. Forest workers store seedlings temporarily under a reflective tarp.

sheet (36 by 18 inches), with tops exposed and roots enclosed (Fig. 7). A moisture-holding medium such as sphagnum or peat moss is then packed around roots for additional protection. This "jelly roll" is slipped into the planter's bag, and trees are extracted one at a time for planting [6].

"Jelly rolling" increases costs (about $6 to $8/1,000 trees, 1981 prices) and probably is not necessary in locations or during periods where atmospheric stress is low. However, such protection is worth the cost when planting is anticipated during periods of relatively high climatic stress [6].

22.8.2.4 Insulated planting bags

Planting bags insulated with polyurethane foam (Fig. 8) or similar materials can be used to protect seedling roots when climatic conditions become warm and dry. Waterproof bags with foam linings are particularly effective in keeping trees moist and cool during the hours required to plant the number of trees they contain. Uninsulated canvas bags may permit root drying during this time.

22.8.2.5 The planting operation

During planting, seedlings may be beyond the direct control of planting supervisors and at the mercy of the planters. To avoid damaging root exposure, planters must remove seedlings from planting bags one at a time. Carrying several seedlings in the hand from planting spot to planting spot will permit roots to dry out.

Planters must not constrict roots into a tight mass before planting or strip laterals from the root system. These actions

Figure 7. Seedlings being "Jelly rolled" to protect roots from desiccation during planting.

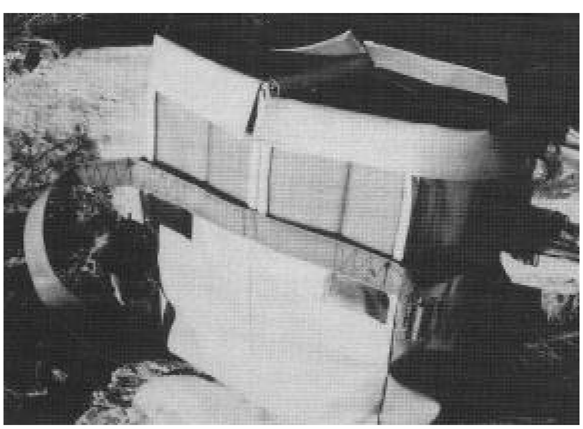

Figure 8. A waterproof planting bag with insulating insert, used for protecting seedlings during planting.

damage roots and reduce the ability of the tree to cope with problems associated with all planting sites.

The importance of careful seedling handling was recently demonstrated with bareroot Monterey pine (*Pinus radiata* D. Don) seedlings [1]. Control seedlings were carefully hand lifted from nursery beds, while all others were removed by a belt lifter. All seedlings were packed directly into rigid boxes. Root abrasion caused by normal lifting and soil removal was noted, and survival and growth data were recorded for several classes of root damage. The seedlings were then transported to planting sites and planted from the boxes, greatly reducing the number of handling steps. Growth and survival were compared after 6 months for batches of seedlings stored for 13 and 20 days. Storage conditions were not described. Control (hand lifted) seedlings in both storage categories averaged 21.6 cm tall and 4.5 mm in diameter; survival was 100%. Machine-lifted seedlings stored 13 days suffered the most damage; they averaged 11.1 cm tall and 2.2 mm in diameter, with 93% survival; machine-lifted trees stored 20 days averaged 8.1 cm tall and 2.2 mm in diameter, with 37% survival. These findings clearly indicate that seedlings handled carefully can be stored for at least 3 weeks with no adverse effects and that trees handled roughly deteriorate even after very short storage periods.

22.9 Conclusions and Recommendations

- Once bareroot seedlings are lifted, they are extremely vulnerable to adverse environmental conditions and difficult to protect in the field. The seedling's need for tender loving care must be given highest priority.

- Seedling damage is cumulative. Each instance of substandard treatment decreases the seedling's ability to perform up to the capability of the planting site.

- Adverse environmental conditions during processing, storage, and transportation include temperatures above 2 to 3°C (35 to 37°F); relative humidities below 90% or PMS above 5 bars; and rough handling resulting in physical damage.

- Nursery managers and customers must maintain close communications to assure that substandard seedling performance is accurately diagnosed so that proper corrective measures can be taken.

Responsibility for plantation success or failure must be shared. Planters and silviculturists cannot perform miracles with stock that has been carelessly produced any more than nursery managers can guarantee stock performance in spite of sloppy field handling. The understandable tendency of nursery managers and customers alike to hold the other responsible for plantation failure must be tempered by mutual understanding of each other's problems and mutual trust in each other's professional abilities. The practice of field foresters visiting nurseries in Oregon and Washington to observe operations and discuss stock characteristics is quite well established; nursery managers must put forth an equal effort to visit customer plantations.

Production of forest-tree seedlings must be viewed *not* as an end in itself, but as a means to an end: seedlings are produced to replace trees harvested from the forest. Everyone involved in production and planting must look beyond the green, healthy-looking seedling to the ultimately more meaningful measure of success—the established plantation.

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