Maintaining Stock Quality After Harvesting
by Thomas D. Landis and Diane Haase

Nursery plants are in a period of high risk from when they leave the protected environment of the nursery to when they are outplanted. Good guidelines for proper care during this critical time have been published for bareroot nursery stock (DeYoe 1986, USDA 1989), and the same guidelines apply to container plants. During handling and shipping, nursery stock may be exposed to many damaging stresses including extreme temperatures, desiccation, mechanical injuries, and storage molds (Table 1). This is also the period of greatest financial risk because nursery plants have reached their maximum value right before shipping (Paterson and others 2001). Adams and Patterson (2004) concluded that improper handling of nursery stock was a more important factor than the type of outplanting tool.

Nursery stock is at its maximum quality immediately before harvesting. Although nursery folks know that their plants are alive and perishable, once seedlings leave the nursery bed or greenhouse they will be handled by many other people who lack this understanding. Stressful injuries can occur at any of the steps between lifting from the nursery and outplanting. Outplanting success is dependent on maintaining plant quality by minimizing stress at each phase of the operation. It is useful to think of plant quality as a chain in which each link represents one of the sequences of events from harvesting and storage at the nursery until planting at the outplanting site (Figure 1). The cumulative effect of the various stresses can be much greater than the sum of separate effects (McKay 1997).

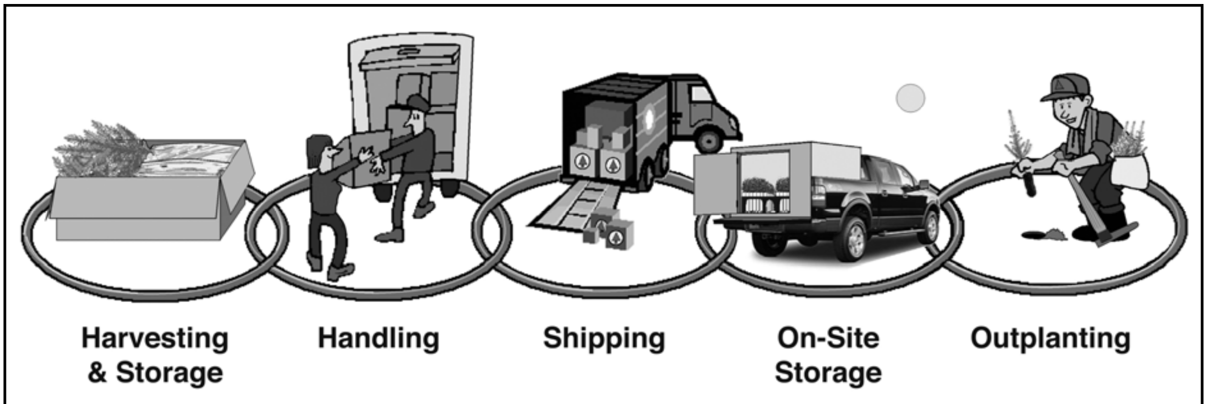

Figure 1 - Nursery plants are subjected to a series of stresses from the time they are harvested to when they are outplanted. Each stage in the process represents a link in a chain, and overall plant quality is only as good as the weakest link.

Table 1 - Nursery plants are subjected to a series of potential stresses from harvest through outplanting

Process	Potential Levels of Stress			
	Temperature Extremes	Desiccation	Mechanical Injuries	Storage Molds
Nursery Storage	High	Low	Low	Medium
Handling	Medium	Medium	High	Low
Shipping	Medium	Medium	High	Medium
On-Site Storage	High	High	Low	High
Outplanting	High	High	High	Low
Levels of Stress	Low	Medium	High	

As stress increases, the plant shifts energy from growth to damage repair. Physiological functions are damaged and survival and growth are reduced. These effects are exacerbated further when plants are outplanted on harsh sites.

Three stresses are most common after stock leaves the nursery: moisture, temperature, and physical (McKay 1997).

1. Moisture stress. Desiccation is the most common stress encountered during shipping, handling, and storage at the field site (on-site storage), and can have a profound effect on survival and growth. Plant water potential influences every physiological process and can greatly reduce growth even if survival is unaffected. These damaging effects can persist for several seasons after outplanting.

Roots are the most vulnerable to desiccation because, unlike leaves and needles, they have no waxy coating or stomata to protect them from water loss. Fine root tips have a greater moisture content than woody roots and are most susceptible to desicciation. If fine roots appear dry, then they are probably already damaged although it is difficult to quantify the amount of injury in the field. When exposed for just 5 minutes, bareroot conifer seedlings exhibited increasing moisture loss with increasing air temperature and wind speed (Figure 2). This shows the critical importance of keeping nursery plants cool, out of direct sunlight, and protected from drying winds.

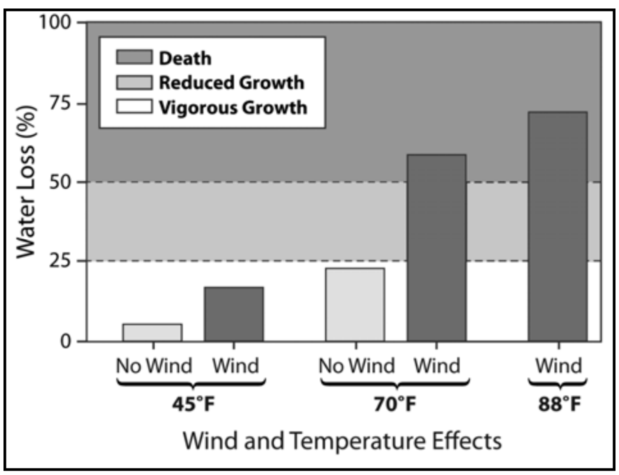

Figure 2 - When bareroot conifer nursery stock was exposed for 5 minutes, plant moisture loss increased with higher temperatures and wind until plant survival and growth were adversely affected. Modified from Fancher and others (1986).

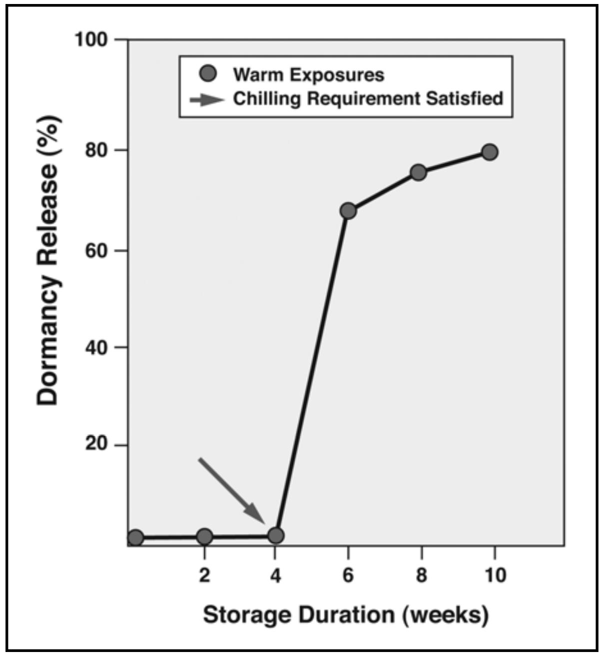

*Figure 3 – Cooler-stored Norway spruce (*Picea abies*)seedlings exposed to short periods of warm temperatures (17 °C [63 °F]), rapidly broke dormancy once the chilling requirement had been met. Modified from Hanninen and Pelkonen (1989).*

Fortunately, roots of container plants are protected somewhat by the growing medium, which serves as a reservoir of water and nutrients. If the plug is allowed to get too dry, however, desiccation damage can be severe. Once roots have dried, subsequent growth reductions are inevitable, even when shoot water potential recovers (Balneaves and Menzies 1988). Dormant conifer plants are more vulnerable to damage from root exposure than dormant hardwood plants because their foliage continues to transpire through storage, shipping, handling, and outplanting.

Moisture stress can be avoided by making sure plugs are kept moist (but not saturated) throughout their journey from nursery to outplanting. Container stock should be irrigated 1 to 2 days before harvesting depending on weather conditions (Fancher and others 1986). This allows the plugs to drain to field capacity; saturated media is unhealthy for roots, increases shipping and handling weight, and increases the potential for storage molds.

2. Temperature stress. Either hot or cold temperature extremes can quickly reduce the quality of nursery plants during handling and shipping. Exposure to improper temperatures can damage stock in several ways:

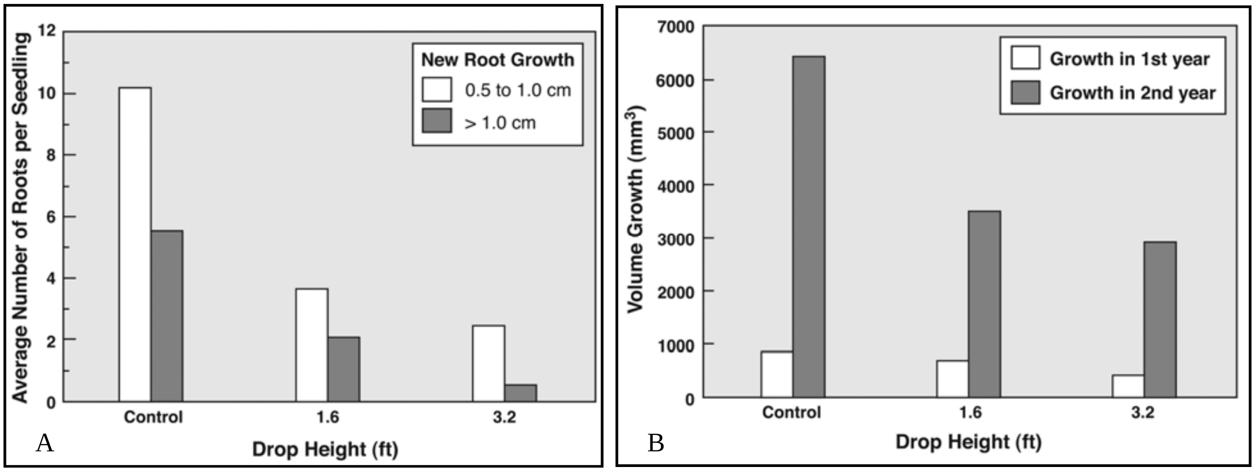

Figure 4 - When bags of conifer seedlings were dropped from different heights, their ability to produce new roots (root growth capacity) was significantly reduced (A). This mechanical injury still affected plant growth 2 years after outplanting (B). Modified from Stjernberg (1996).

Increased hazard from storage molds - Pathogenic fungi, such as Botrytis mold, can survive in all types of storage and may grow rapidly during shipping in the humid environment of a storage bag or box if the temperatures are too warm. Increased carbon dioxide from plant respiration in storage and shipping containers is also thought to stimulate fungal development. There have been anecdotal reports of storage mold "blowups" in boxes of freezer stored nursery stock after only a few days exposure to ambient conditions.

Loss of bud dormancy - Nursery plants that are stored overwinter are harvested at peak hardiness, which is ideal for storage, shipping, and handling. When ready for outplanting, properly stored plants have had their chilling requirements fully satisfied, and cold temperature is the only environmental factor that prevents resumption of growth. Once the chilling requirement has been met, exposing stored nursery stock to even a short period of warm temperatures will rapidly break dormancy (Figure 3).

Moisture stress - Stagnant air within the storage or shipping bag or box is a poor heat conductor, but direct sunlight and wind can rapidly increase plant temperatures and cause serious moisture stress.

Heat stress - Remember that stored nursery plants are alive and respiring. This means, when plants are exposed to warm temperatures, their respiration adds heat to their environment and this is particularly serious in closed environments such as storage bags or boxes. Maintaining good air circulation in storage areas, especially non-refrigerated storage, will minimize heat build-up due to plant respiration.

Freezing damage - Although not as widely appreciated, freezing temperatures can also damage nursery stock. Because they are much less cold-hardy, roots are much more susceptible than shoots to freeze damage. Ambient and in-box temperatures should be monitored regularly; temperature monitoring equipment is now inexpensive and readily available. Freezing damage has even occurred in cooler storage during shipping because of equipment failure. This is common because refrigeration units on shipping vans are notoriously fickle and air circulation is restricted. Boxes in the front of the van near the refrigeration units will necessarily be colder than those in the back. Resist the temptation to overpack trucks and leave adequate space for good air circulation (Rose and Haase 2006). Stock that has been cooler stored should be shipped at these same temperatures (0.5 to 1 ^{o}C [33 to 34°F]), whereas frozen stock can be shipped under warmer temperatures to begin the thawing process.

3. Physical stresses. Boxes of nursery plants are handled many times from when they leave the nursery until the plants are finally outplanted (McKay 1997). Rough handling can result in reduced plant performance after outplanting. Each person involved in the handling and shipping of nursery stock should receive training on how to minimize physical stresses.

The potential for physical damage to nursery stock can come from dropping, crushing, vibrating, or just rough handling. It's easy to forget that nursery plants are alive when they are in boxes. Studies have shown that the stress of dropping boxes of seedlings reduced root growth potential, decreased height growth, increased mortality, and increased fine-root electrolyte leakage (Tabbush 1986; Sharpe and others 1990; McKay and

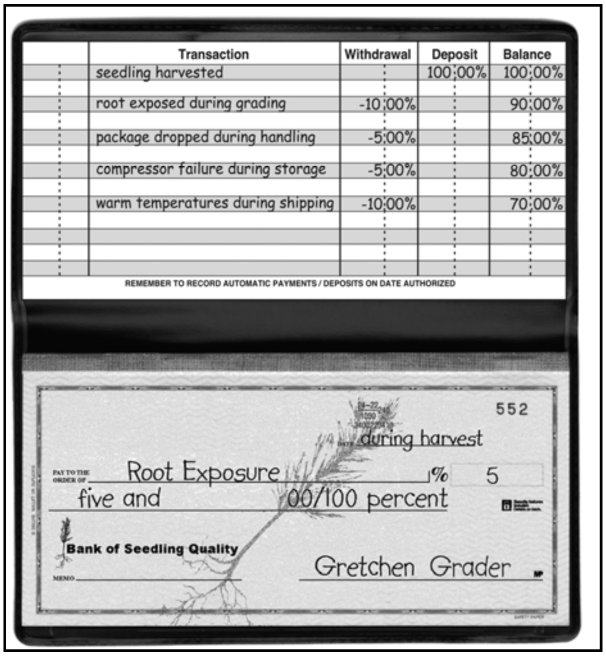

Figure 5 - It is useful to think of nursery plant quality as a checking account in which all types of abuse or stress are withdrawals. Note that all stresses are cumulative and no deposits can be made – it is impossible to increase plant quality after nursery harvest.

others 1993). Stjernberg (1996) did a comprehensive evaluation of the physical stresses that nursery stock is subjected to during transport from the nursery to the outplanting site. Root growth capacity tests on boxes of cooler stored white spruce (*Picea glauca*) seedlings showed fewer new roots were produced as the distance the box was dropped increased (Figure 4A). Interestingly enough, volume growth of these seedlings still showed growth depression 2 years after outplanting (Figure 4B).

Accumulated stresses. It is relatively easy to identify and correct individual stresses during storage, shipping, handling and outplanting. However, it is much more difficult to measure the cumulative effects of different stresses (McKay 1997). Because all types of abuse or exposure are cumulative, it is helpful to think of nursery plant quality as a checking account. Immediately before harvesting, plants should be at 100% quality, but all subsequent stresses are withdrawals from the account (Figure 5). It is impossible to make a deposit—nothing can be done to increase plant quality after leaving the nursery.

Summary and Conclusions

Nursery plants are at their peak of quality before lifting but, once harvested, they are exposed to a variety or stresses during handling, storage, and transport. Moisture stress, especially desiccation of roots, can severely impact subsequent growth and survival after outplanting. Even short exposures to cold temperatures can injure or kill plant tissues. Exposure to warm temperatures can accelerate the loss of bud dormancy as well as increase development of storage molds. Mechanical damage caused by rough handling is also a risk factor for nursery plants during every step of the way from nursery to outplanting. All these stresses are cumulative and can combine to reduce nursery plant quality. However, through careful handling and attention to minimize potential stresses, high plant quality can be maintained until outplanting.

References

Adams, JC, Patterson WB. 2004. Comparison of planting bar and hoedad planted seedlings for survival and growth in a controlled environment. In: Connor KF, editor Proceedings of the 12th Biennianl Southern Silvicultural Research Conference. Asheville (NC): USDA-Forest Service, Southern Research Station. General Technical Report GTR SRS-71; 423-424.

Balneaves JM, Menzies MI. 1988. Lifting and handling procedures at Edendale Nursery-effects on survival and growth of 1/0 *Pinus radiata* seedlings. New Zealand Journal of Forestry Science 18:132-134.

DeYoe D.1986. Guidelines for handling seeds and seedlings to ensure vigorous stock. Corvallis (OR): Oregon State University, Forest Research Laboratory. Special Publication 13. 24 p.

Fancher GA, Mexal JG, Fisher JT. 1986. Planting and handling conifer seedlings in New Mexico. Las Cruces (NM): New Mexico State University. Cooperative Extension Service Circular 526. l0p.

Hanninen H, Pelkonen P. 1989. Dormancy release in *Pinus sylvestris* L. and *Picea abies* (L.) Karst. seedlings: effects of intermittent warm periods during chilling. Trees 3(3): 179-184.

Hitch KL, Shiver BD, Borders BE. 1996 Mortality models for newly regenerated loblolly pine plantatioins in the Georgia Piedmont. Southern Journal of Applied Forestry 20: 197-202.

McKay HM. 1997. A review of the effect of stresses between lifting and planting on nursery stock quality and performance. New Forests 13(1-3):369-399.

McKay HM, Gardiner BA, Mason WL, Nelson DG, MK. 1993. The gravitational forces generated by dropping plants and the response of Sitka spruce seedlings to dropping. Canadian Journal of Forest Research 23: 2443–2451.

Paterson J. DeYoe D, Millson S, Galloway R. 2001. In: Wagner RG, Colombo SJ, editors. Regenerating the Canadian forestprinciples and practice for Ontario. Markham (ON): Ontario Ministry of Natural Resources and Fitzhenry & Whiteside Ltd:325-341.

Rose R, Haase DL. 2006. Guide to reforestation in Oregon. Corvallis (OR): Oregon State University, College of Forestry. 48p.

Sharpe AL, Mason WL, Howes REJ. 1990. Early forest performance of roughly handled Sitka spruce and Douglas fir of different plant types. Scottish Forestry 44: 257–265.

Stjernberg EI. 1996. Seedling transportation: effect of mechanical shocks on seedling performance. Pointe-claire (QC): Forest Engineering Research Institute of Canada.Technical Report TR-114. 16 p.

Tabbush PM. 1986. Rough handling, soil temperature, and root development in outplanted Sitka spruce and Douglas-fir. Canadian Journal of Forest Research 16: 1385–1388.

USDA. 1989. A guide to the care and planting of southern pine seedlings. Atlanta (GA): USDA Forest Service, Southern Region. Management Bulletin R8-MB39. 44 p