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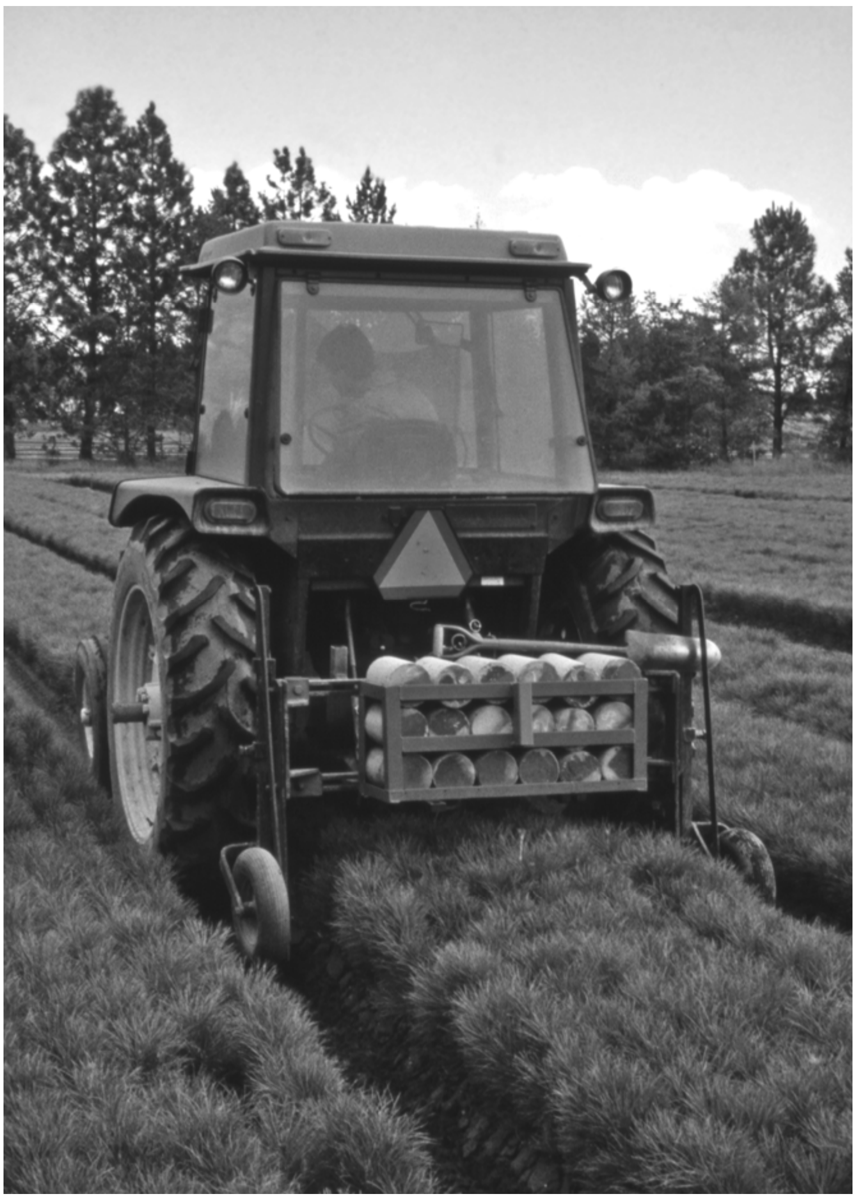

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Nursery Meetings

This section lists upcoming meetings and conferences that would be of interest to nursery, reforestation, and restoration personnel. Please send us any additions or corrections as soon as possible and we will get them into the next issue.

The 2008 Western Forest and Conservation Nursery Association (WFCNA) meeting will take place in Missoula, Montana June 23 to June 25, 2008. June 26 is an optional day for those who would like to stay for a white water rafting trip. We have an exciting agenda this year. The first day will be dedicated to energy efficiency and alternative energy in the nursery: growers will present their experience using alternative energy or implementing cultural practices that reduce energy costs. During the second day, we will address general nursery topics with an emphasis on alternative growing media for container production. An agenda will be available soon. For more information contact:

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The Southern Forest Nursery Association (SFNA) meeting will be held in Asheville, North Carolina on July 22 to July 24, 2008 at the Crown Plaza Resort. There will be 3 half day sessions of presentations and 2 field trips. One will be to North Carolina Forest Service Linville Nursery and one will be to the Biltmore Estate for a tour of where the science of forestry was first practiced in the US. For more information contact:

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A special joint meeting of the Eastern and Western Regions of the International Plant Propagators' Society (IPPS) will be held at the Denver Marriott City Center in Denver, Colorado on September 14 to September 17, 2008. In addition to tours of local nurseries, the presentations will highlight propagation techniques, new plants, and plant breeding and selection with an emphasis on the Rocky Mountain region. For more information, check-out the IPPS website: www.ipps.org/WesternNA

The 29th Intermountain Container Seedling Growers' Association meeting is set for October 7 to October 9, 2008 in Coeur d'Alene, Idaho. Updates will be available at http://seedlings.uidaho.com as they become available. For more information contact:

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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).

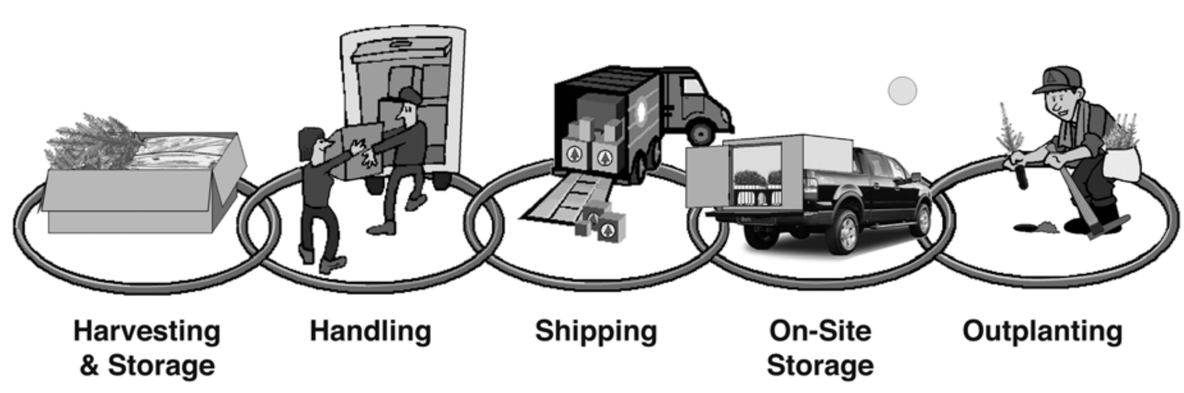


Figure 1 - Nursery plants are subjected to a series of stresses from the time they are harvested to when they are outplanted. Each stage in the process represents a link in a chain, and overall plant quality is only as good as the weakest link.

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 desiccation. 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.

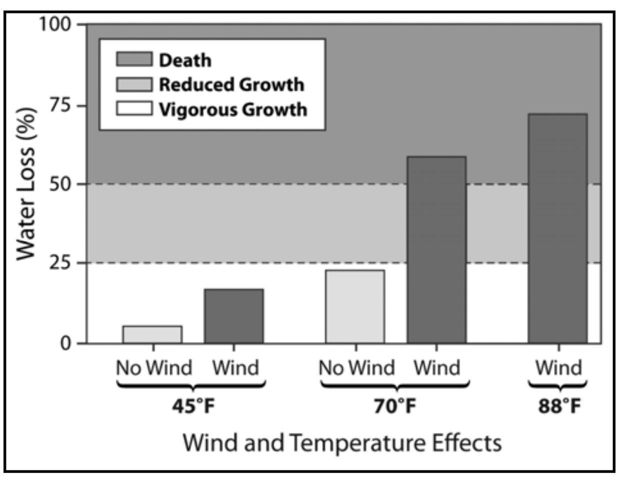


Figure 2 - When bareroot conifer nursery stock was exposed for 5 minutes, plant moisture loss increased with higher temperatures and wind until plant survival and growth were adversely affected. Modified from Fancher and others (1986).

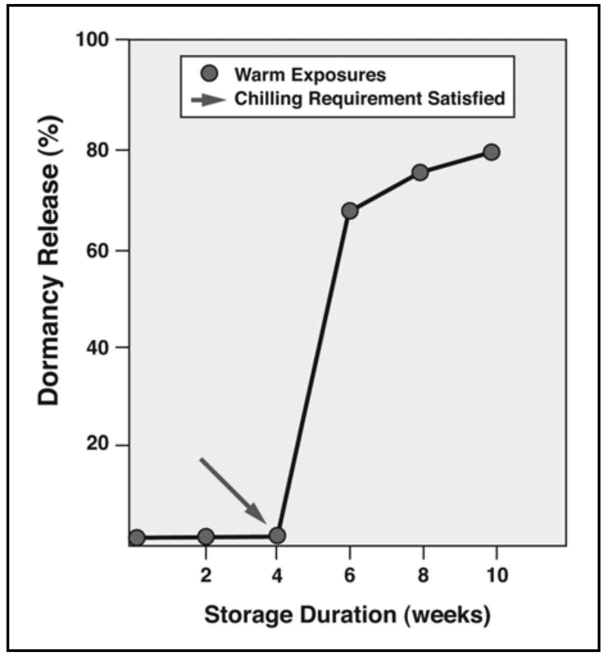
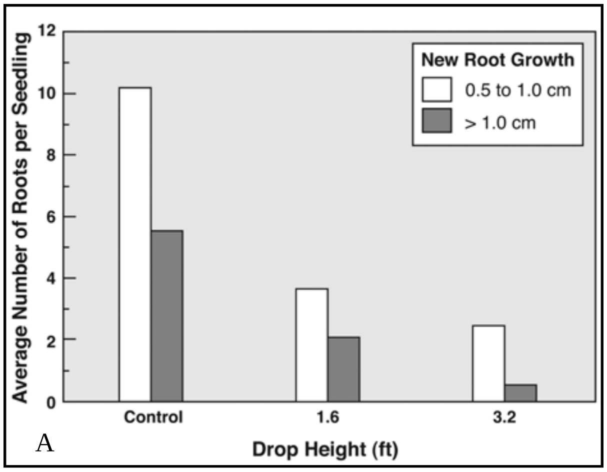


*Figure 3 – Cooler-stored Norway spruce (*Picea abies*)seedlings exposed to short periods of warm temperatures (17 °C [63 °F]), rapidly broke dormancy once the chilling requirement had been met. Modified from Hanninen and Pelkonen (1989).*

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:



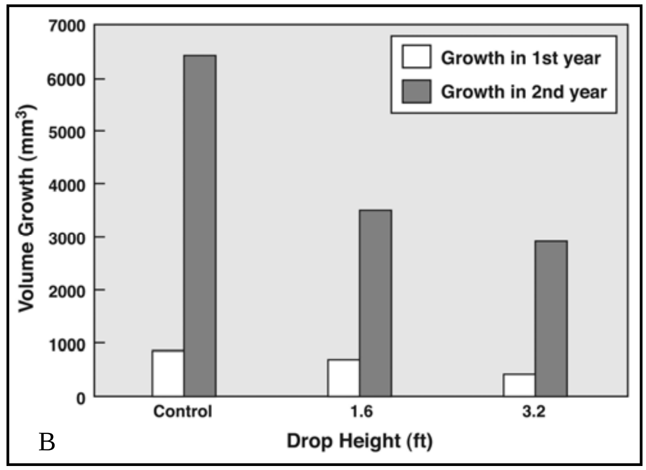


Figure 4 - When bags of conifer seedlings were dropped from different heights, their ability to produce new roots (root growth capacity) was significantly reduced (A). This mechanical injury still affected plant growth 2 years after outplanting (B). Modified from Stjernberg (1996).

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

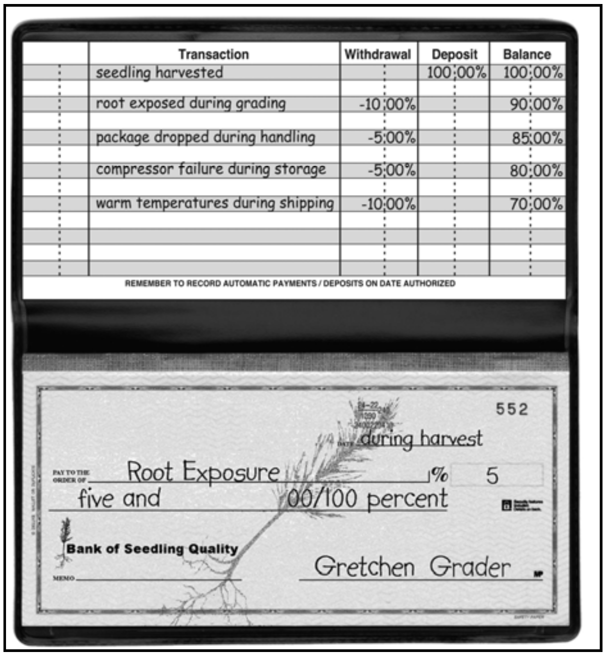


Figure 5 - It is useful to think of nursery plant quality as a checking account in which all types of abuse or stress are withdrawals. Note that all stresses are cumulative and no deposits can be made – it is impossible to increase plant quality after nursery harvest.

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.

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Root Culturing in Bareroot Nurseries
by Thomas D. Landis

Tree seedlings are a unique crop. We spend most of our time and effort in the nursery to produce a healthy, vigorous shoot, and most cultural activities are scheduled according to shoot phenology and growth. This is understandable as the shoot is the part of seedling that we can easily observe. Roots are, however, the business end of a seedling. One of the sayings that I frequently use in training sessions is that "tree seedlings are a root crop". While it may seem technically inaccurate to compare seedlings to carrots or potatoes, I think that the analogy is useful in getting growers to consider the importance of properly culturing root systems. Even the best nursery stock will fail after outplanting if the roots are not functioning properly and can rapidly grow out ("egress") into the surrounding soil.

The history of root culturing - Culturing roots in bareroot nurseries is nothing new. The classic nursery manual "Nursery Practice on the National Forests", which was printed in 1917, has an entire section on root pruning. In the ensuing years, root pruning was mentioned only sporadically in the nursery literature because of a lack of effective mechanized equipment.

The most influential research on root culturing came from "down under" in the late 1960s and early 1970s. The New Zealand Root Pruner featured a thin, serrated blade which oscillated back and forth to precisely cut seedling roots. These new root culturing procedures of undercutting and wrenching produced seedlings with dense fibrous root systems that were previously only available with transplants (Van Dorrser and Rook1972.). To confirm their quality, outplanting trials of root cultured 2+0 seedlings showed good survival and growth. Undercutting, lateral pruning and wrenching had become standard nursery practices in most conifer nurseries by the 1980s (Duryea 1984, 1986). *Forest Nursery Practice* (1994) devotes an entire chapter to root culturing. This practice is also discussed in detail in the *Bareroot Stock Production* chapter in *Regenerating the Canadian Forest: Principles and Practice for Ontario* (Mohammed and others 2001).

Root culturing of hardwood seedlings took a little longer to develop. With the increased demand for broadleaved nursery stock since the early 1990s, more research was undertaken on hardwood nursery culture, especially the root systems. McNabb (2004) reported that root culturing of hardwoods in southern nurseries was primarily used to control shoot height. In a recent survey of southern hardwood nurseries, however, undercutting, lateral pruning and wrenching were commonly implemented based on customer preference (Vanderveer 2005).

Table 1 - Root culturing in bareroot nurseries: terminology and operational uses

Term	Function	Cultural Objective	Implement	Timing
Undercutting	Cut roots in a horizontal plane in the root zone	1) Encourage root fibrosity 2) Reduce shoot height 3) Stimulate budset	Sharp fixed blade, or oscillating blade covering full bed width	Once to several times per season, or prior to harvesting
Vertical or lateral pruning	Cut roots in a vertical plane between rows	1) Encourage root fibrosity 2) Facilitate harvest	Sharp fixed blades or coulters spaced be-tween rows	Once to several times per season, or prior to harvesting
Box pruning	Cut roots in 3 dimensions: bottom, between rows, and between plants in a row	1) Encourage root fibrosity 2) Facilitate harvest	Three step process: 1) Undercutting 2) Vertical pruning between rows 3) Hand pruning within rows	Just before harvesting
Wrenching	Induce moisture stress and loosen soil within rooting zone	1) Control shoot height 2) Stimulate budset 3) reduce soil compaction	Dull fixed blade set at an angle covering full bed width	Once to several times per season
Root Pruning	This is done on the grading table after harvest and should be called bench pruning			

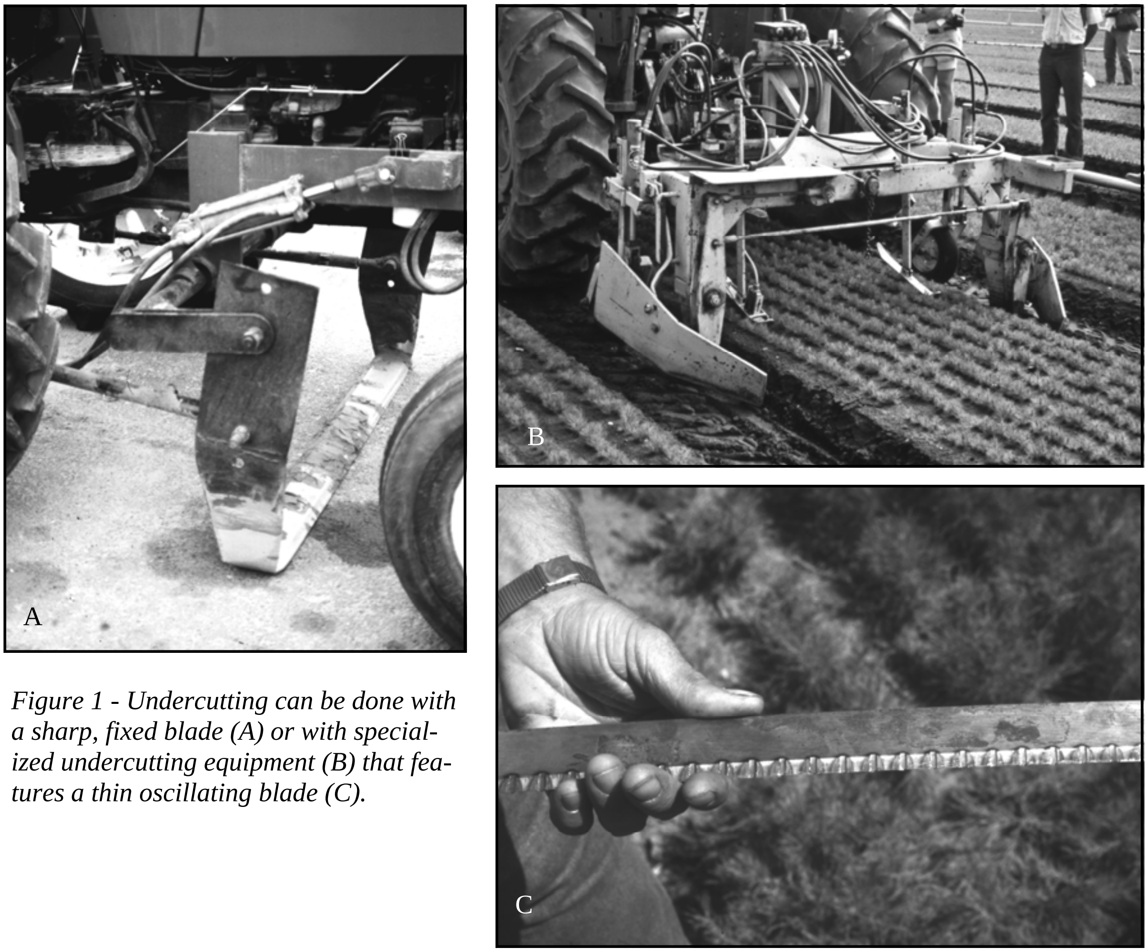


Figure 1 - Undercutting can be done with a sharp, fixed blade (A) or with specialized undercutting equipment (B) that features a thin oscillating blade (C).

Root Culturing Treatments. Reading through the published literature or talking to nursery workers, you'll find the terms used for root culturing can be rather confusing and sometimes contradictory. Updating my 1989 FNN article with the latest published literature (Menes and McDonough 1994), I came up with the following definitions (Table 1):

Root culturing - This is a general term for any nursery cultural practice designed to modify root growth or morphology while the seedling is still in the nursery bed

Undercutting - This can be done with either a sharp fixed blade (Figure 1A) or thin oscillating blade (Figure 1B-C) that is pulled along a horizontal plane in the root zone of the nursery bed. The undercutting action severs the taproot and all other roots extending beyond the regulated depth of the blade. Oscillating blades work well in sandy soils, but fixed blades are needed for nurseries challenged by heavier-textured soils; neither works well in rocky soils. Based on nursery surveys, 95% of Pacific Northwest nurseries (Duryea 1984) and 57% of southern conifer nurseries (Duryea 1986) undercut their stock.

Vertical or lateral pruning (sidecutting) - This root pruning treatment severs seedling roots in a vertical plane by pulling sharp blades or coulters between the rows. The positioning of the cutters must be carefully monitored so that they travel halfway between the rows of seedlings (Figure 2A). Therefore, lateral pruners are belly-mounted so that they can be controlled by the tractor driver or pulled behind the tractor and controlled by a separate operator (Figure 2B). Some nurseries lateral prune their stock during the growing season, and this root culturing treatment is also popular just before harvesting. Ninety-five percent of Northwest nurseries (Duryea 1984) and 72% of southern nurseries (Duryea 1986) lateral prune their stock.

Box pruning - Box pruning consists undercutting followed by vertical pruning between rows and between plants. (See discussion in Mechanical Pruning).

Wrenching - This multi-purpose root culturing treatment consists of pulling a thick, angled blade (20° to 30°) at specified depths under the seedbeds (Figure 3A). Wrenching can be used in any soil texture except highly compacted silts and clays and, like undercutting,

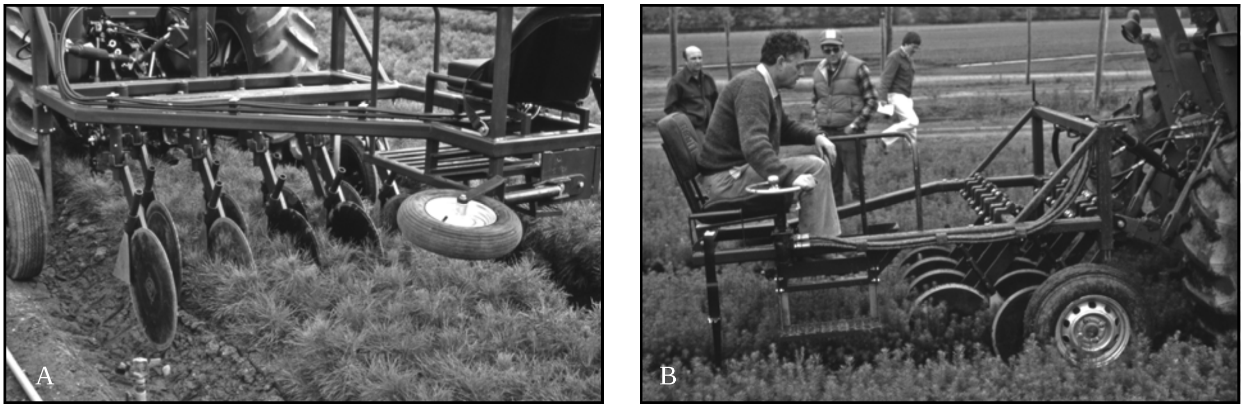


Figure 2 - Lateral pruning equipment must be carefully positioned between the rows of seedlings (A), and so is either belly-mounted or pulled behind the tractor with a separate operator (B).

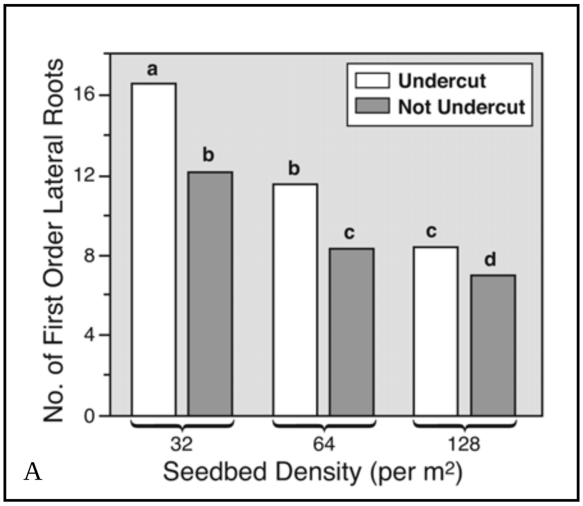
cannot be used in rocky soils. Because the angled blade tends to plane upwards, extra weights are need to keep the blade in the proper plane (Figure 3A). Because wrenching blades are not as effective in cutting roots, this operation is easier and more effective when done immediately after a separate undercutting. In addition to its effects on root morphology, wrenching is also used to loose and aerate the soil in the root zone (Figure 3B). This is especially effective to increase water infiltration and improve air exchange in compacted seedbeds. Based on surveys, 80% of bareroot conifer nurseries in the Pacific Northwest (Duryea 1984) and 35% in the south (Duryea 1986) wrench their seedlings.

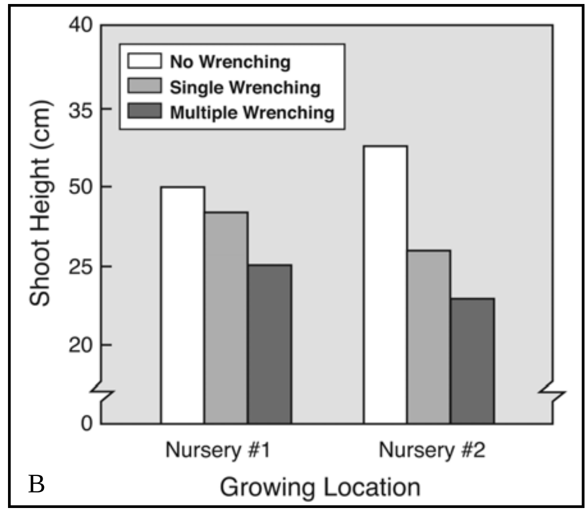
Root pruning - This term should only be applied to trimming roots to desired length specifications during grading.

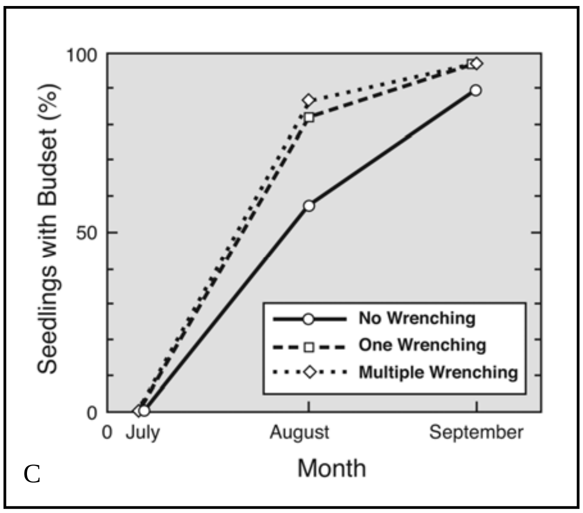
Root Culturing Objectives. Nurseries apply root culturing treatments for a variety of reasons:

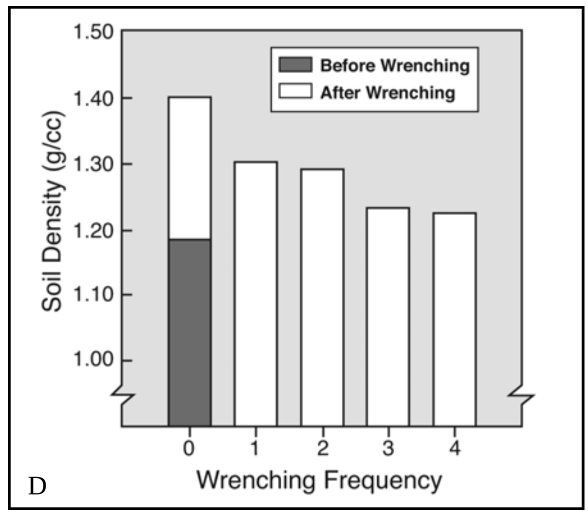
1. To create a compact and fibrous root system, especially of tap-rooted species. In tests with loblolly pine (*Pinus taeda*), frequent root culturing greatly changed root morphology, resulting in more compact root systems with more fine roots and better mycorrhizal development. (Dierauf and others 1995a). Longleaf pine (*Pinus palustris*) seedlings that received vertical pruning (sidecutting) had more fibrous roots and had significantly better outplanting survival than unpruned stock (Hatchell and Muse 1990). Some broadleaved seedlings have heavy stiff lateral roots that are often broken and lost during harvesting. Undercutting increased the number of first order lateral roots in northern red oak at 3 different bed densities (Figure 4A).

Figure 3 - Wrenching (A) is a multipurpose root culturing treatment that, in addition to cutting roots, can be used to counteract the negative effects of soil compaction within the root zone (B).









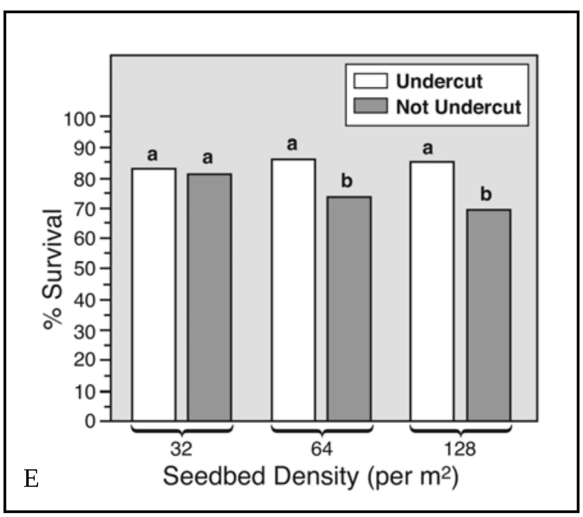


Figure 4 - One of the most common root culturing objectives is to create a more fibrous root system, especially with tap-rooted plants (A). Another is to reduce shoot height (B) and create a stockier plant with thicker caliper and more roots. Wrenching is used to create moisture stress and induce budset (C), especially with species that are difficult to bring into dormancy. Nursery soils naturally become compacted and so wrenching is applied at intervals during the growing season to reduce bulk density (D). The ultimate objective of any root culturing treatment is to increase outplanting performance, such as increased survival in northern red oak (E). Figures A and E modified from Schultz and Thompson (1997), B and C from Duryea (1998), D from Miller and others (1985).

2. To control shoot height, decrease the shoot-to-root ratio, and create a seedling with transplant-like characteristics. Research done with Douglas-fir seedlings (*Pseudotsuga menziesii*) showed that undercutting followed by wrenching was effective in controlling shoot height at 2 different nurseries (Figure 4B). With white spruce, black spruce (*Picea mariana*) and jack pine *(Pinus banksiana*), root pruned and wrenched seedlings were shorter and had larger root systems than the controls, resulting in better shoot-to-root ratios (Buse and Day 1989).

3. To encourage bud dormancy and condition plants for storage and outplanting - This is a major objective for species that continue to produce shoot growth late into the season, such as the southern pines (May 1985). In New Zealand, Monterey pine (*Pinus radiata*) do not set bud during their first year so root wrenching therefore is used to stop shoot growth and promote budset (van Dorsser and Rook 1972). In a controlled study, Douglas-fir seedlings set bud faster and more completely after wrenching (Figure 4C).

4. To reduce soil bulk density and counteract compaction - Wrenching creates a physical and moisture stress that help control excessive shoot height. It is also used to minimize the soil compaction that inevitably occurs due to heavy equipment use. In a loblolly pine nursery, the soil bulk density increased almost 20% during one growing season (Figure 4D). When this soil was wrenched, soil bulk density declined as wrenching frequency increased (Miller and others 1985). Compaction is even worse in heavier soils, and so wrenching would be even more effective.

5. Increase the yield of shippable seedlings. Root culturing can be used to keep plants from exceeding shoot height specifications. For example, precision sown and undercut Douglas-fir and Scots pine (*Pinus sylvestris*) had higher yields of shippable seedlings than the control (Deans and others 1989).

6. Improve outplanting performance. Of course, the ultimate objective of any nursery treatment is to increase survival and growth after outplanting. In one study, outplanting survival of eastern white pine (*Pinus monticola*) was substantially increased by an average of 18% by root culturing (Dierauf and others 1995b). In another with Douglas-fir, Sitka spruce (*Picea sitchensis*) and Scots pine (Mason and others 1989), undercut plants grown at the lowest bed density had the best survival and growth after outplanting. Hardwood seedling quality is highly correlated with the number of first order lateral roots (FOLR). When northern red oak (*Quercus rubra*) nursery stock was root cultured (Schultz and Thompson 1997), the improved root system resulted in improved outplanting survival (Figure 4E).

Conclusions and Recommendations

In my mind, there is no doubt that root culturing works—the problem is using the right tool, in the right way, and at the right time. So, here are my thoughts on how to plan and implement a root culturing program at your nursery:

1. Define your objectives - Root culturing operations can have variable effects, and many nursery managers make the mistake of trying to achieve several different objectives with one operation. Root culturing can affect seedling morphology and physiology in several ways: control height growth, modify shoot-to-root ratio, increase root fibrosity, induce seedling moisture stress, and so on. Your objective will define what implement you use, how you use it and, most importantly, the timing of the operation. A root culturing treatment that is being applied to control shoot height may not increase root fibrosity at the same time.

On the other hand, don't apply root culturing treatments as a matter of general policy. If you don't know why you are doing an operation, then don't do it - any root culturing treatment induces some measure of stress, which can be harmful. Cultural operations that are applied "for good measure" usually do more harm than good.

2. Properly time root culturing practices - This is the tough one. Don't try to schedule cultural operations by the calendar because of variations in weather from year to year and species/weather interactions. Get away from your desk and computer and go take a look at your seedlings. Yes, the root system is difficult to observe but take a shovel with you and dig up some seedlings every few weeks during the growing season. Observations of phenology and measurements of relative shoot and root growth should be recorded and plotted to provide a permanent record. Shoot growth and root growth are often inversely related so, after a few years of collecting these measurements, you should have enough personal experience and data to permit estimation of root activity based on shoot phenology. With blue oak (*Quercus douglassii*) seedlings, the timing of the undercutting was critical to control both root fibrosity and shoot height (Krelle and McCreary 1992). They recommend undercutting as early in spring as possible and again in mid-summer. The first pruning should be as shallow as possible without dragging under the young seedlings and the second pruning should be about two to three inches below the first pruning.

3. Synchronize root culturing with other nursery activities and soil conditions - Root culturing should not be viewed as an independent operation. Irrigation, in particular, will affect the success of root culturing operations. Again, get out and check the soil profile with a shovel rather than guess whether the soil is at the proper moisture content because the surface appears wet. The proper moisture content will also vary depending on your objectives: wrenching requires relatively dry soils for thorough fracturing, whereas undercutting or sidecutting are most efficient when relatively moist soils promote smooth movement of the blade.

4. Select the right implement for the job - In my mind, wrenching does not do a good job of cutting seedling roots in many situations. If the objective is to promote a more fibrous root system, I would consider undercutting rather than wrenching. Because of the thickness and angle of the blade, root wrenching equipment will often drag seedling roots instead of clearly cutting them. It is often necessary to undercut seedlings with a thin sharp brace before attempting a wrenching operation, particularly with tap-rooted species or older seedlings. If the objective is to induce moisture stress to control top growth, I would try wrenching and pass the blade completely under the root zone to fracture the soil and break soil-root contact.

5. Follow-up and evaluate the operation - Both undercutting and wrenching require follow-up irrigation to avoid damaging moisture stress. Wrenching, in particular, creates a severe moisture stress and heavy irrigation is normally required to repack the soil particles around the seedling root system. The timing and amount of irrigation will depend on cultural objectives, weather, soil type, and individual species response.

Nurseries are busy places, and many times growers will go on to the next activity without ever checking back to see if the root culturing worked or not. It's hard to assess the effects of any cultural operation at the end of the growing season if you haven't taken the time to observe the physiological and morphological effects following the operation.

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Mechanical Root Pruning in Container Nurseries
by Thomas D. Landis and Don Willis

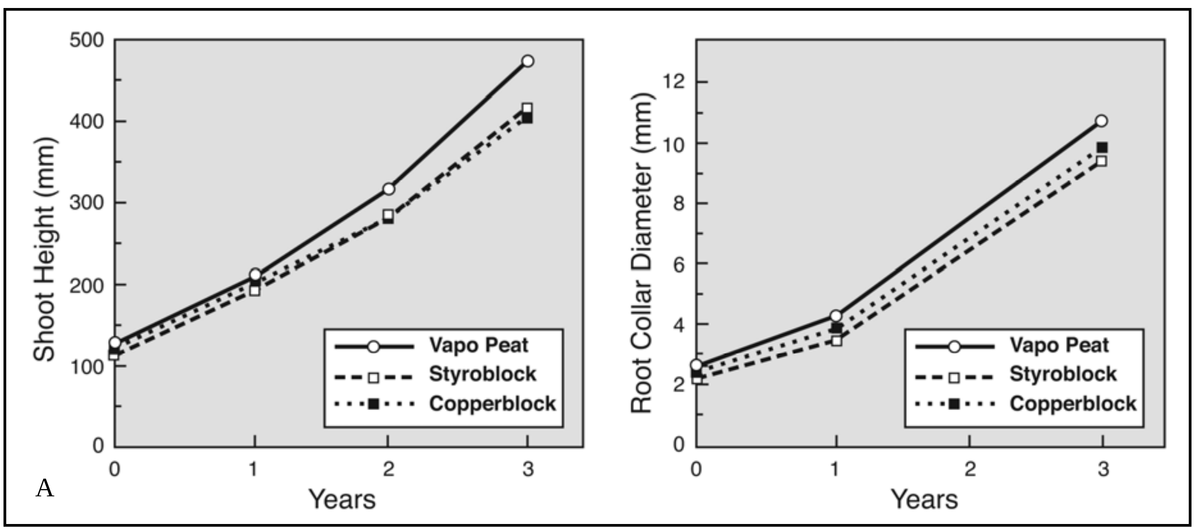
Trees and other native plants have aggressive root systems when can become physically distorted and physiologically impaired when grown in containers. These “root-bound” plants can fail to perform after outplanting and there have been instances of plantation failure from “toppling”. Numerous articles have been written on the problem and at least 2 symposia have addressed root deformation in containers (Hulten 1982; Van Eerden and Kinghorn 1978).

Attempts to remedy the root deformation problem have taken 3 approaches, and we discussed the first two in past FNN issues:

1. Chemical pruning - This involves coating the interior walls of the container with a chemical that inhibits root growth. Cupric carbonate ($CuCO_3$) and copper oxychloride are commonly used. The chemical barrier causes roots to be chemically pruned at the container wall. These pruned roots become suberized but will begin to grow again after outplanting (Landis and others 1990).

2. Air pruning - Roots in all types of containers become air pruned when they reach the drainage holes along the bottom, and dry air causes roots to quit growing. Sideslit or airslit containers use this same concept on the sides as well as the bottom and field trials show that air pruned roots grow out rapidly after outplanting. A wide variety of these type of containers are commercially available (Stuewe 2008).

3. Mechanical pruning - This third option has been the least studied, primarily because the root pruning had to be done by hand which made it cost prohibitive. The classic research on mechanical pruning of bareroot seedling roots was done in New Zealand back in the



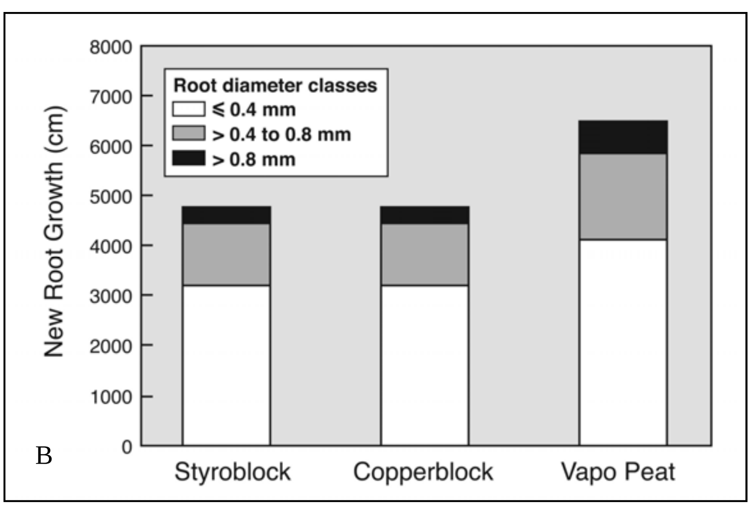


Figure 1 - Mechanically boxed pruned Vapo seedlings outperformed stock grown in Styroblock™ or Copperblock™ containers: shoot height (A) root collar diameter (B), and amount of new roots, (C). Modified from Krasowski and Owens (2000).

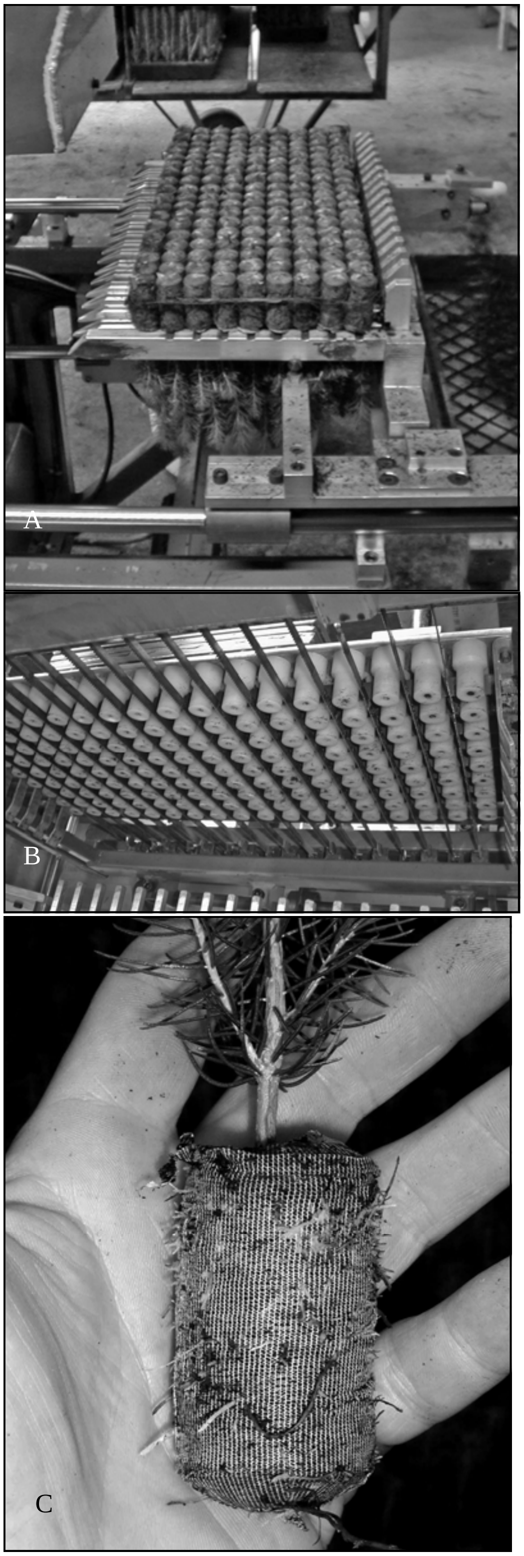


Figure 2 - The Jiffy® root pruning machine (A) has thin saw blades that cut root between Jiffy plugs in both directions (B), which produces a box-pruned seedling that is ready for outplanting (C). Photos by Don Willis.

1970s and early 1980s where they developed a new three-dimensional root culture called "box pruning". Box pruning consists of the vertically cutting lateral roots in all planes around the root system. Seedlings to be box-pruned must be precision sown, so that they are equally spaced within each row. A lateral root pruner is used to cut roots between the rows, and then the roots between seedlings in the are hand cut with a spade (Brunsden 1981). Outplanting trials of box-pruned nursery stock were very favorable, but the practice has not been widely adopted because of the hand labor involved.

Mechanical or box pruning of container stock has not been possible except for seedlings grown in blocks of peat-based growing media. For example, the Vapo system consists of a block of compressed peat moss with holes drilled in the top at regular spacing for seed placement. The peat block is placed in a plastic tray with slots on all sides to allow mechanical root pruning. The result is a box-pruned container seedling with roots cut on all sides. In a recent research trial with white spruce (*Picea glauca*) container stock (Krasowski and Owens 2000), box-pruned Vapo seedlings were compared to standard Styroblock™ stock and seedlings grown in Styroblock™ containers commercially treated with copper (Copperblock™). When measured 3 growing seasons after outplanting, the mechanically-pruned seedlings had significantly greater shoot height and stem diameter than the Styroblock™ and Copperblock™ seedlings (Figure 1A). The mechanically pruned Vapo seedlings also had better root egress in different 3 root size classes, compared to seedlings from Styroblock™ or Copperblock™ containers (Figure 1B).

One of the tree species that has shown the most problems with root deformation after outplanting has been lodgepole pine (*Pinus contorta*). In a comparison study, mechanically pruned container seedlings had less root deformation than conventionally produced stock in Copperblock™ conainers. (Krasowski1995).

Most nursery folks are familiar with Jiffy® pellets which consists of compressed peat moss surrounded by a thin plastic mesh. The pellets are arranged in a plastic tray, and one of the challenges of the Jiffy pellet system has been to prevent roots growing between the pellets. Recently, the Jiffy engineers developed an innovative mechanical root pruning machine (Figure 2A) that cuts roots between the cells in both directions (Figure 2B). The result is a mechanically box pruned seedling that should perform very well after outplanting (Figure 2C).

The Jiffy Mechanical Root Cutter has 2 loading stations and a variable speed motor which allows for different cutting cycle times depending on the amount of root pruning required between the pellets. An average cutting cycle time can range between 10 to 20 seconds. The equipment is designed to invert the tray, remove the carrying tray, and then the plastic insert before pushing the seedlings into the protected cutting area. This allows seedlings to be root pruned upside down (pellets exposed) without damaging the foliage (Figure 2A). The 2 sets of blades operate in 2 directions simultaneously, and this cross-cut action keeps pellets positioned properly during the full cycle. When finished cutting, the carrying tray is placed back over the pellets and inverted for carrying the seedlings to a holding area or to packing stations.

For more information on the Jiffy root pruning equipment, contact Don at:

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Hot-planting Opens New Outplanting Windows at High Elevations and Latitudes
by Thomas D. Landis and Douglass F. Jacobs

In North America, forest and native plant nurseries grow most of their stock for the traditional outplanting windows during the winter and spring. Outplanting success has been best at these times because frequent precipitation keeps soil moisture high, and low solar input reduces transpirational water losses low (Figure 1).

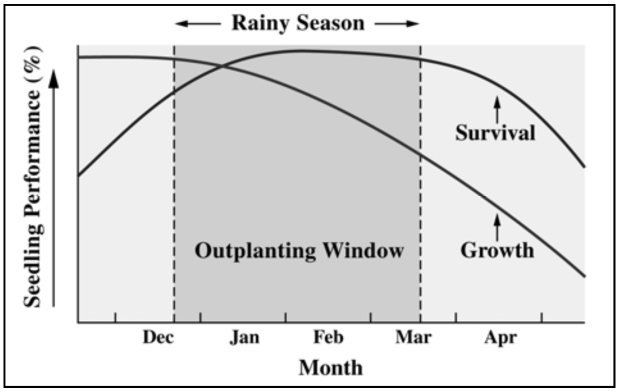

Figure 1 - Most North American nursery stock is outplanted during the tradtional windows of winter and early spring.

To meet customer's demands, nurseries grow their stock the year before, harvest them in the early winter and store them until the outplanting sites are ready. In locations where late winter or early spring outplanting is possible, this means a few weeks to several months of storage. Nurseries do a good job of hardening plants to endure the stresses of harvesting, storage, shipping, and outplanting. If refrigerated storage is possible, the stock is packaged in specially-designed bags or boxes to protect the plants and minimize water loss. Other nurseries store their plants in open or sheltered storage until they can be shipped to customers. These practices and scheduling have become so routine that nurseries and their customers don't think much about them at all.

Is Overwinter Storage Necessary?

I like to stress that long-term storage is primarily an operational necessity rather than a physiological requirement for several reasons:

Facilitating harvesting and shipping - The large numbers of plants being produced at today's nurseries means that it is physically impossible to lift, grade, process, and ship all stock at the same time. Therefore, one of the primary benefits of storage facilities is that they help to "spread-out" scheduling and processing during the busy harvesting and shipping seasons.

Distance between nursery and outplanting site - Many nurseries are located at great distances, often hundreds or even thousands of miles, from their customers. The further the distance from nursery to outplanting site, the greater the need for storage.

Differences between the lifting window at the nursery and outplanting windows. Nurseries are often located in different climates than their customers to take advantage of milder climates and longer growing seasons. This is especially true in the mountainous west where nurseries must be located in valleys at lower elevations that have drastically different climates than higher elevation outplanting sites.

Therefore, eliminating the need for long-term storage would save considerable hassle and expense as well as avoid the numerous risks of holding plants overwinter.

What is "hot-planting"?

As the name suggests, "hot-planting" is when nursery stock is harvested, shipped, and outplanted without long-term refrigerated storage. For the reasons listed above, hot-planting is not very common nowadays. Looking back, however, long-term storage wasn't needed when all nurseries were established close to their outplanting sites. Plants were dug up in the nursery one day and shipped and outplanted within a few more. Back then, transportation was slow and plant handling and packaging was rather simple. Knowing what we now do about plant physiology and stock quality, it's amazing how well those early plantations performed.

Although hot-planting has been used in both bareroot and container nurseries, it is currently making a comeback with container stock. Here are a couple of examples:

1. Fall outplanting at high elevations in western North America - On most reforestation and restoration sites, soil moisture is the overriding limiting factor to plant survival and growth. On high elevation outplanting sites, however, cold soil temperatures may be as important or perhaps even more important a limiting factor as soil moisture. Access to high elevation planting sites may be restricted by snow that may not melt until late June (Figure 2A), or even July (Jacobs 2004). That melting snow keeps soil temperatures cool and, because root growth of a wide variety of native species is restricted below 10 ^{o}C (50 ^{o}F) (Figures 2B and 2C), these cold temperature can be limiting to outplanting success.

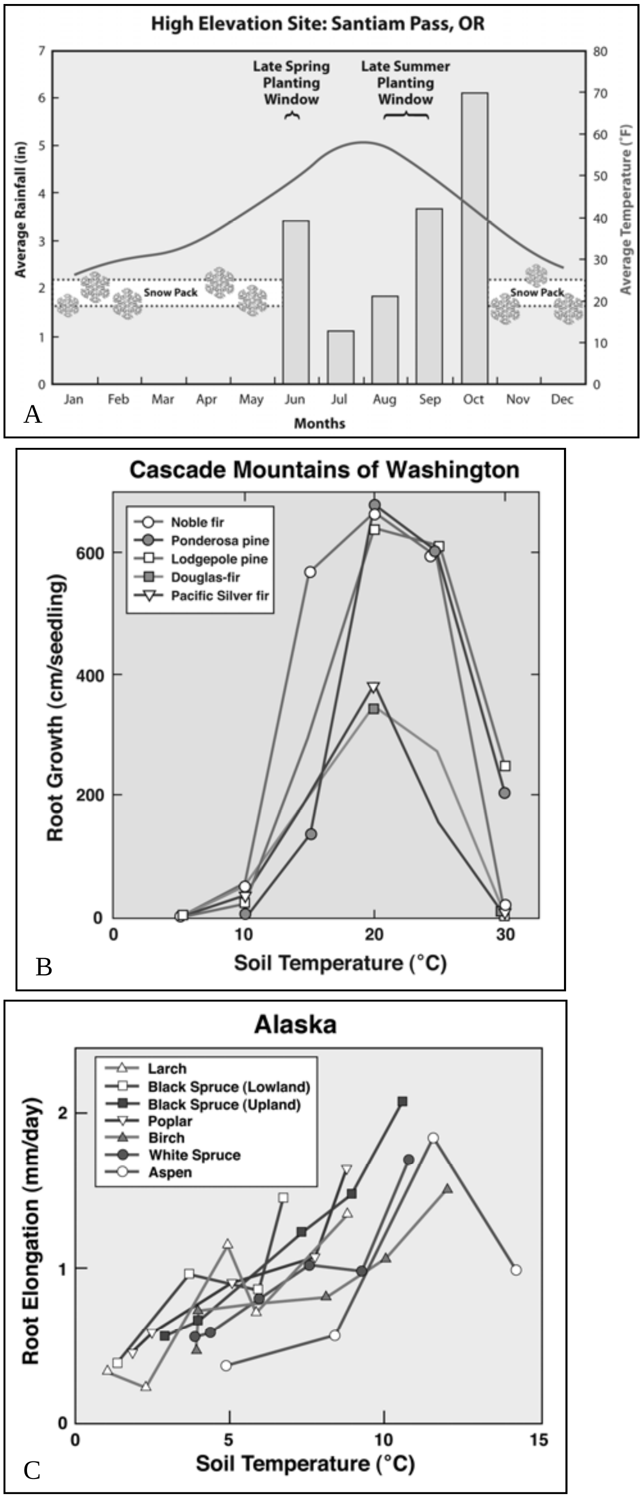

Figure 2 - Access to high elevation outplanting sites can be delayed until late spring or even early summer due to persistent snows (A). Research with tree seedlings from both high elevations (B) and high latitudes (C), has shown that roots do not grow or take up water in cold soils. B modified from Lopushinsky and Max (1990); C modified from Tryon and Chapin (1983).

So, container plants are being outplanted in the fall to take advantage of warmer soils so that they can produce enough new roots to become established before winter. This allows plants to become conditioned to the local environment and break bud and grow rapidly the following spring (Faliszewski 1998). The success of these outplantings is very site dependent, however, and hot-planted stock needs to be properly conditioned.

2. Summer outplanting in boreal Canada and Scandinavia - Instead of the typical late spring outplanting, experience has shown that the outplanting window can be extended into summer months. Summer outplanting projects are also being driven by a shortage of skilled planters and the growing use of planting machines. Recent research has shown that summer outplanting can be effective. In Finland, for example, Norway spruce (*Picea abies*) and silver birch (*Betula pendula)* seedlings have been successfully hot-planted from mid-June through early-August. The importance of warmer soil temperatures has been proven by better root egress during these summer outplantings than during the traditional outplanting window of late May (Louranen and others 2004, 2006). Summer outplanting has also been widely used at northern latitudes in western Canada (Revel and others 1990) and occasionally in the mountains of the Pacific Northwest and Rocky Mountains. For example, in 2005 more than half of approximately 40 million planted white spruce (*Picea glauca*) seedlings in Alberta, Canada were outplanted during the summer (Tan and others 2008).

Blackout as a Hardening Tool

One of the main reasons for the recent resurgence of hot-planting is the use of short-day ("blackout") treatments to harden nursery stock before summer or fall outplanting. Although primarily used at high latitude nurseries (>45°) in Canada and Scandinavia, blackout has recently proven effective in northern California (Jacobs and others 2008).

Originally used to control flowering in greenhouse flower crops, blackout has recently been adapted to forest nurseries. A successful blackout system must do 3 things (Jopson 2007):

1. Light must be reduced to low enough levels to trigger budset and induce hardening—

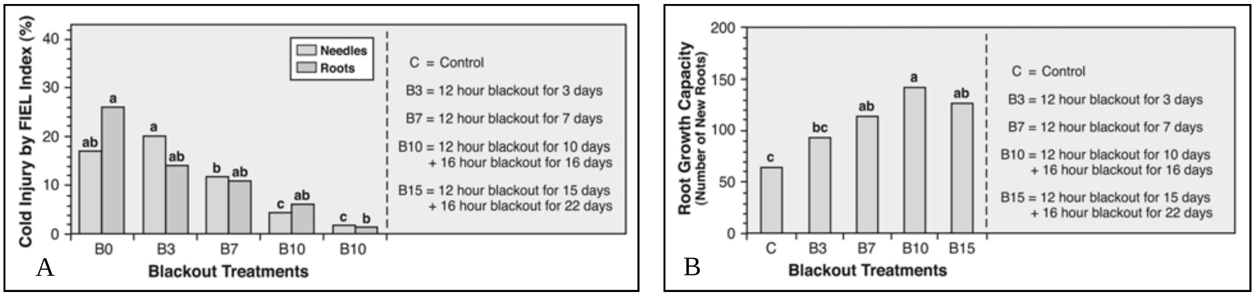

Figure 3 - Short-day treatments ("blackout") helped condition white spruce seedlings for summer outplanting by increasing cold hardiness (A) and new root egress (B). Modified from Tan and others (2008).

approximately 3 foot-candles (30 lux) for northern California species. Research has shown that blackout treatments as short as one week can be effective although 3 to 6 weeks may be needed for less responsive species and seed sources (Jopson 2007). In Norway, the proper blackout treatment varies with seed source and nursery location (Kohmann and Johnsen 2007).

2. Coverings must be porous to prevent the buildup of high temperatures and humidity which can stress plants and negate the effectiveness of the blackout treatment.

3. Blackout curtains must be easily applied to completely cover the crop. Although hand installation is effective, it is time-consuming and labor-intensive for large-scale operations. Automated blackout curtains are commercially available and can be retrofitted to most propagation structures.

Although moisture, mineral nutrients, temperature, and daylength are all used to induce dormancy and hardiness, blackout is the only treatment that can be successfully employed during summer or early fall without the risk of damaging stress. Recent research with white spruce in northern Canada (Tan 2007) found that blackout treatments induced cold hardiness of both needles and roots (Figure 3A) and stimulated root egress after outplanting (Figure 3B). This is important because frost injury to foliage and frost heaving have both been cited as serious drawbacks to summer or fall outplanting.

Interestingly enough, almost no research has been done on whether blackout could be used to harden bareroot stock for hot-planting. The few tests that have been done show that it could be effective inducing dormancy and hardiness during summer (Kohmann 2008; Rikala 2008). Blackout curtains have been installed on metal hoops over container stock being grown outdoors so this same technology could work in bareroot beds. It would be interesting to see some operational research on this promising cultural treatment.

The Importance of Rapid Root Egress

For hot-planting to succeed, nursery stock must "hit the ground running". Plants must be conditioned to immediately initiate new roots that will grow out into the surrounding soil. Not only is this important to avoid serious moisture stress but rapid root egress is critical to avoid frost heaving later in the fall. In soon-to-be-published research with white spruce container stock in northern Alberta, new root egress was found to be highly correlated with survival, shoot growth, and stem diameter growth (Figure 4).

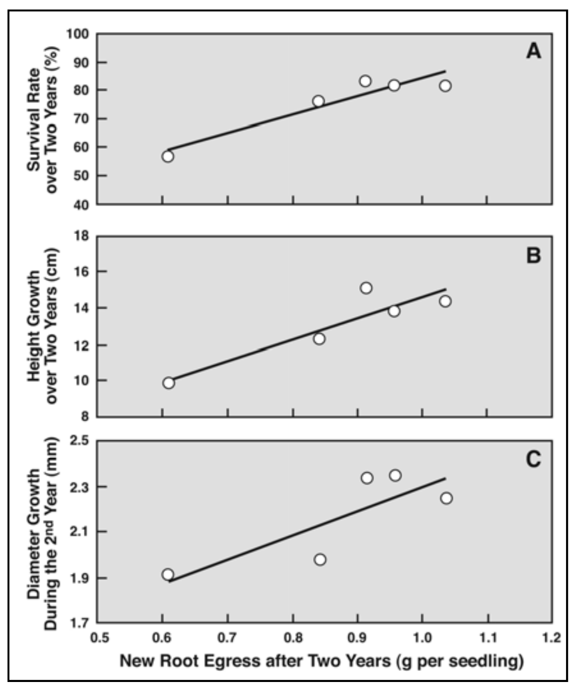

Figure 4 - New root egress was critical to the outplanting success of white spruce container seedlings in northern Alberta: survival (A), shoot growth (B), and stem growth (C). Modified from Tan and others, in press.

Operational aspects of hot-planting. The key to a successful hot-planting operation is careful coordination between the nursery and the planter.

Stock should be packed upright in cardboard boxes without plastic bag liners which can reduce air exchange and increase respirational heat build-up. Using white boxes will help to reflect sunlight and keep in-box temperatures cooler (Kiiskila 1999).

Hot-planted stock is more sensitive to shipping and handling stresses than fully-dormant and hardy plants. Increasing shipping distances from 6 to 75 miles did not cause a noticeable effect but, interestingly enough, plant height was reduced 3 years after outplanting— the longer the shipping distance, the greater the effect (Luoranen and others 2004).

On the outplanting site, nursery stock should be stored upright and kept in the shade. Irrigating seedling plugs immediately before outplanting was found to significantly increase the survival of hot-planted birch and spruce seedlings (Luoranen and others 2004).

Summary

Hot-planting will never replace traditional winter or spring outplantings, but does deserve a second look when site conditions warrant. Eliminating overwinter storage has many benefits from both biological and operational standpoints. The key to successful hot-planting is good planning and close coordination between nursery and customer.

Although it can be used for both bareroot and container stock, container nurseries have more cultural options to induce dormancy and hardiness before shipping. Shortening daylength with blackout curtains has proved very effective for inducing budset and increasing cold hardiness. Species and seed sources have shown considerable variability in their response to blackout, however, and so trials are needed to establish the best treatment.

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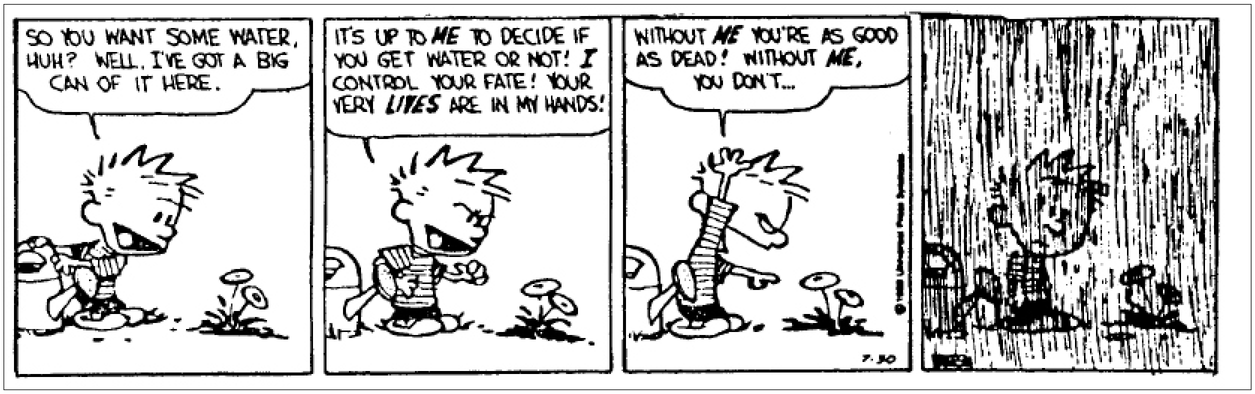
Horticultural Humor



New Nursery Literature

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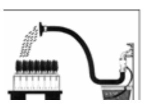

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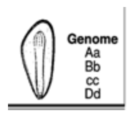

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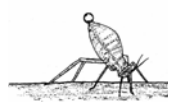

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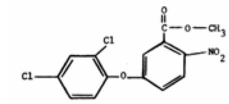

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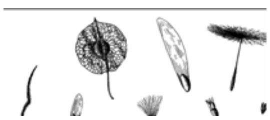

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