An Evolution of Bareroot Cultural Practices at J. Herbert Stone Nursery

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In: Riley, L . E.; Dumroese, R. K.; Landis, T. D., tech. coords. 2006. National Proceedings: Forest and Conservation Nursery Associations-2005. Proc. RMRS-P-43. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 160 p. Available at: http://www.rngr.net/nurseries/publications/proceedings

Abstract: Bareroot nursery practices that maximize root development and root growth have been studied and documented over a number of years. Each nursery, however, has its own unique combination of climate, soils, species, and stocktypes for which site specific cultural practices are necessary. J. Herbert Stone Nursery, a USDA Forest Service nursery in Central Point, OR, has completed a variety of production trials to adapt general cultural practices to its site. These trials resulted in 1) developing a strategy to maintain high soil porosity through the application of organic matter and tillage measures; 2) sowing seeds earlier in the winter for 1 + 0 stocktypes; 3) lowering seedbed densities from 267 seedlings/m^2 (25 seedlings/ft^2) to between 161 and 195 seedlings/m^2 (15 and 18 seedlings/ft^2); 4) transplanting seedlings in early fall instead of spring; and 5) developing a miniplug + 1 stocktype.

Keywords: seedling culture, root volume, *Pseudotsuga menziesii*, *Pinus ponderosa*, root culture

Introduction

Production of planting stock with balanced shoot-to-root ratios and large, vigorous root systems to match the needs of the outplanting site is a key element in successful seedling establishment. Although reforestation sites in the Pacific Northwest are extremely variable, the characteristic most commonly shared is a long summer with little to no moisture from June through September. Seedling survival under these conditions requires rapid root growth early in the growing season to maximize water uptake and to compete with vegetation on the site. Good root development in the nursery, therefore, is important for seedling survival.

Understanding seedling root physiology, including the seasonality of root activity and growth, and the effects of nursery cultural practices on overall seedling physiology is key to improving seedling quality at a production nursery and producing a target seedling that better matches the requirements of outplanting sites (Duryea 1984). Cultural practices that can affect seedling root and shoot development include 1) soil cultivation and amendments; 2) timing of sowing; 3) seedling spacing and seedbed density; 4) timing and depth of root culturing, such as undercutting and wrenching; and 5) timing of transplanting. In addition, the continuing development of alternative, or nontraditional stocktypes can improve root morphology for differing outplanting situations.

Current Nursery Practices

Soil Management

Seedling culturing techniques, including cultivation and entire crop removal, contribute to rapid deterioration of nursery soils. Soils with a low organic content or poor soil structure have low fertility, restricted gas exchange in the rhizosphere, poor drainage, and the potential for increased vulnerability of nursery stock to pathogenic organisms (Duryea 1984). Consequently, an essential part of nursery soil management is the use of organic, and occasionally mineral, amendments. These amendments help maintain or improve soil properties, including bulk density, nutrient holding capacity, soil structure, and the environment for beneficial rhizosphere microorganisms such as nitrifying bacteria and mycorrhizae (Davey and Krause 1980).

Timing of Sowing

Determining the sowing dates for obtaining a target seedling is dependent on the soil and climate conditions of the nursery site. Spring sowing has become the norm for most western bareroot nursery operations, that is, between mid-April and early June. However, inclement weather during the relatively short sowing window may cause delays in sowing operations. Any delay in spring sowing may adversely affect seedling size at the end of the growing season, expose very young seedlings to summer seedbed heat and moisture stresses, and affect timing of dormancy in the fall. As a general rule, sowing is best done as early as possible after the average soil temperature at 10 cm (4 in) exceeds 10 °C (50 °F) (Thompson 1984).

Seedbed Density

Seedbed densities in bareroot nurseries vary widely depending on the species and stocktype. In the Pacific Northwest, densities for 2 + 0 stock can range from 161 to 323 seedlings/m^2 (15 to 30 seedlings/ft^2), with a similar range for 1 + 0 stock (Thompson 1984), although numerous studies have indicated that seedling quality, as well as plantation growth and survival, are improved by sowing seeds at lower bed densities.

Root Culturing

Cultural practices that disturb root systems to alter seedling morphology are common practice in most bareroot nurseries. Root culturing is most commonly used to stop seedling height growth, decrease shoot-to-root ratios, improve root fibrosity, and precondition seedlings for outplanting (Duryea 1984). Undercutting, or horizontal root pruning, causes a loss in apical dominance in the root system, resulting in increased lateral root growth, the development of new tertiary roots, and a more compact, fibrous root system (van Dorsser and Rook 1972), and the effects are largely influenced by the timing and depth of the pruning treatment (Riedacker 1976).

Timing of Transplanting

Seedlings can be transplanted during spring, early summer, or fall, with spring transplanting as the most common practice in the Pacific Northwest. Seedlings transplanted in spring are lifted during winter, stored for an extended period of time, and transplanted in mid- to late spring. Seedlings for early summer and fall transplanting are lifted and immediately transplanted, or transplanted following minimal storage. Spring transplanting often incurs less risk and may result in less variable survival than early summer or fall transplanting (Duryea 1984). Many nurseries, however, have succeeded in transplanting during the fall with good results (Hahn 1990).

Seedling Stocktypes

The traditional stocktypes for most bareroot conifer nurseries have included: 1) 1 + 0 seedlings that are sown directly into the seedbeds and cultured for one growing season; 2) 2 + 0 seedlings that are sown directly into the seedbeds and cultured for two growing seasons; 3) 1 + 1 seedlings which are sown directly into the seedbeds, cultured for one growing season, lifted, transplanted during the fall or spring, and grown for one additional season; and 4) P + 1 seedlings that are grown in containers for one season, extracted, transplanted in the fall or spring, and grown for one additional season. In order to shorten the growing cycle, but still produce a seedling with a well developed root system and balanced shoot-to-root ratio, production of a miniplug + 1 stocktype has been attempted at several bareroot nurseries over the past two decades with good success (Hahn 1990; Tinus 1996). The miniplug + 1 stocktype is started in small containers in the winter, transplanted in the spring, grown during the summer and fall, and lifted the following winter.

While many of these are considered well-established practices, we needed to verify or modify them for local soils, climate, stocktypes, and species.

J. Herbert Stone Nursery Trials

J. Herbert Stone Nursery is a bareroot conifer nursery, administered by the USDA Forest Service, located near Central Point, Oregon at 426 m (1397 ft) elevation. Annual precipitation averages 500 mm (20 in), with more than 90 percent occurring between mid-September and mid-May. Mean annual temperature is 12 °C (54 °F) and the growing season is 220 days (USDA 1989). Soils in the bareroot production area (approximately 86 ha [213 ac]) are deep, sandy loams formed from granitic and metamorphic alluvium. They are coarse-loamy, mixed mesic Pachic Haploxerolls classified as Central Point series. Stone Nursery was established in 1978 to meet the high demand for conifer production for reforestation of Federal lands in the western United States. The site was selected primarily for its warm climate and the potential to produce a 1 + 0 seedling.

Throughout the history of production at Stone Nursery, operational trials and studies have been implemented to improve both production and efficiency in culturing seedling crops. These studies looked at the physical environment, the physiology of various species grown at the nursery, and treatments to manipulate the morphology of seedlings to achieve target specifications. All studies were designed using randomized complete blocks with adequate buffer areas between treatments and blocks. Data sets were analyzed using SAS or similar statistical analysis programs.

Root Growth Periodicity

To gain information that would contribute to more accurate cultural prescriptions for irrigation, fertilization, and root culturing throughout the growing season, a monitoring program to determine the seasonality of root activity and growth was established during two growing seasons to collect soil temperatures, root volumes, and root activity in 1 + 0 and the first and second growing seasons for 2 + 0 Douglas-fir *(Pseudotsuga menziesii)* and ponderosa pine *(Pinus ponderosa)* seedlings.

Year 1—First year patterns of root activity and root volumes differed slightly by stocktype (1 + 0 versus first growing season for 2 + 0 stock) in Douglas-fir (figure 1). Root activity in the 1 + 0 seedlings was high at the beginning of the monitoring period in late summer, when average soil temperatures were around 17 °C (62 °F). Activity dropped off during the fall, but was rising following the occurrence of fall precipitation. Root activity in the 2 + 0 seedlings in the first growing season peaked in mid fall, when soil temperatures ranged from 13 to 16 °C (55 to 60 °F). Root volume growth showed a large increase in the first part of October, with slowing through the fall.

Root activity for both ponderosa pine stocktypes reached an initial peak in mid-October, when soil temperatures ranged from 12 to 14 °C (54 to 57 °F), with a second increase at the end of the monitoring period following initiation of fall precipitation (figure 2). Root volume increased sharply in early to mid-fall (October), with growth slowing in late fall.

Douglas-fir and ponderosa pine 1 + 0 seedlings are cultured differently than 2 + 0 seedlings during their first growing season. The 1 + 0 seedlings are sown earlier in the spring at lower seedbed densities, receive higher levels of

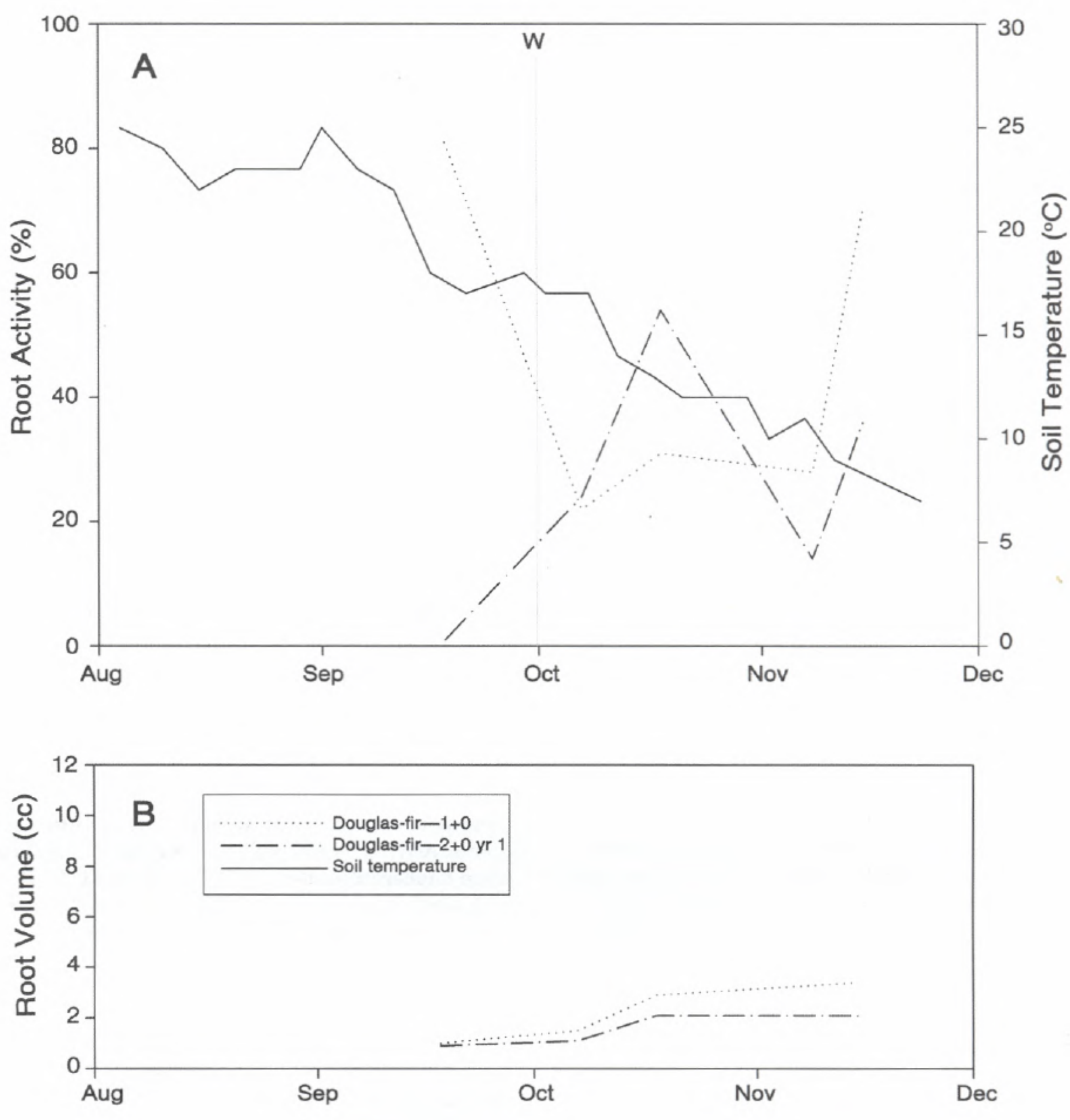

Figure 1—A) Root activity (%) and soil temperatures, and B) changes in root volume for 1+0 Douglas-fir during the fall of the 1988 growing season (W = root wrenching).

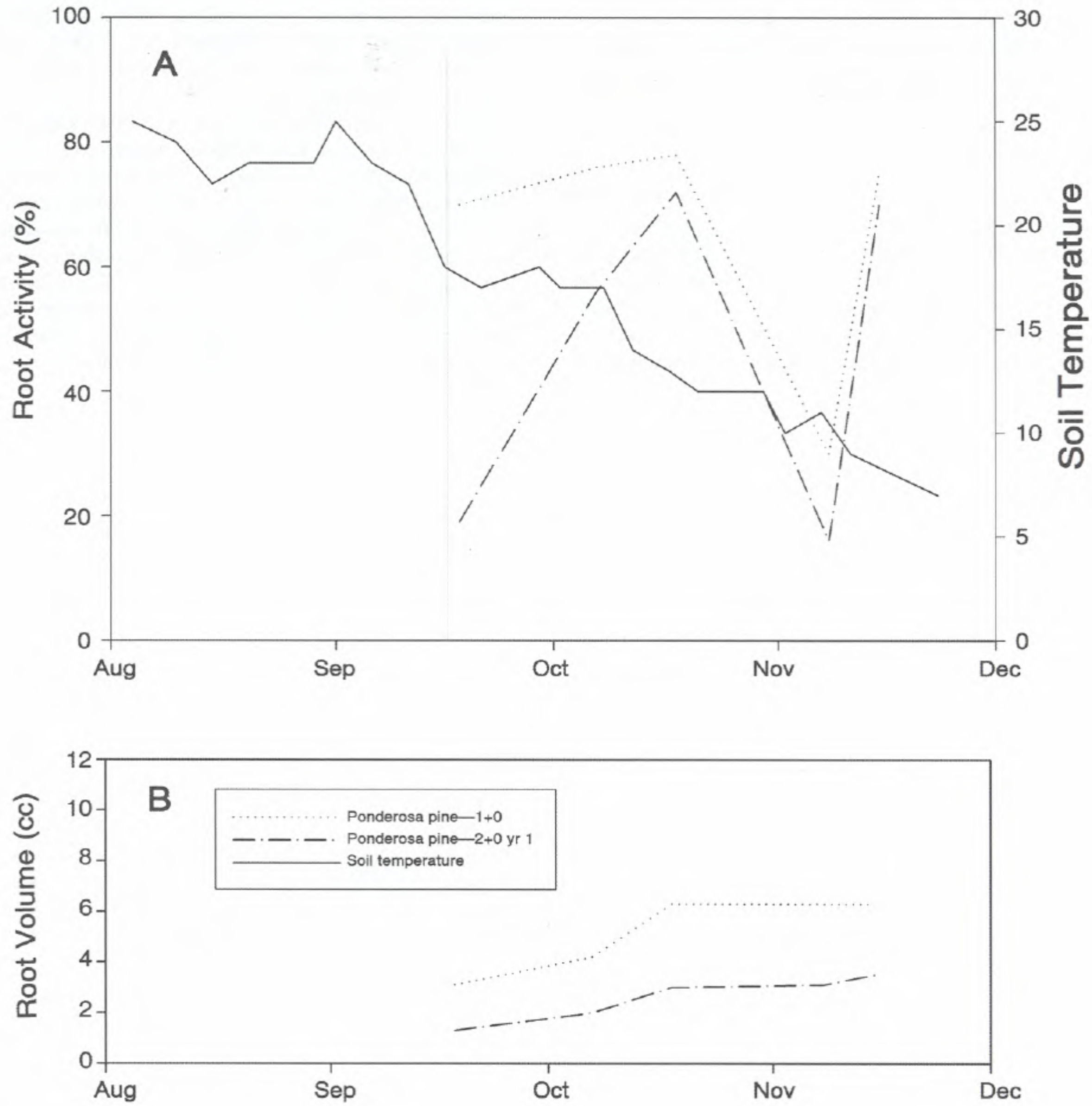

Figure 2—A) Root activity (%) and soil temperatures, and B) changes in root volume for 1+0 ponderosa pine during the fall of the 1988 growing season (W = root wrenching).

both irrigation and fertilization through mid-summer, and are subjected to dormancy induction—that is, water stress—later in the summer than seedlings grown for 2 + 0 stock. As a result, seedlings grown for 1 + 0 stocktypes are larger in both stem diameter and root volume for a more balanced, plantable seedling in the first growing season.

Year 2—Root activity during the second growing season for 2 + 0 Douglas-fir seedlings was high in early spring during both monitoring years, when soil temperatures ranged from 10 to 13 °C (50 to 55 °F). Due to competition for photosynthate, activity decreased to a low level in late spring and continued at low levels through the summer, when soil temperatures averaged around 22 °C (72 °F) but irrigation was necessary to maintain moisture in the soil profile. Activity rose rapidly in late August/early September, when temperatures decreased from 21 to 11 °C (70 to 52 °F), with several peak periods throughout the fall (figure 3). Root volume increased steadily throughout the majority of the growing season, with a large increase in volume occurring in late August through September.

Root activity in 2 + 0 ponderosa pine seedlings was high in the spring of the second growing season, with peaks occurring in late March and late April when soil temperatures ranged between 13 to 16 °C (55 to 61 °F). Irrigation was maintained and, although temperatures reached peaks of 23°C (73 °F), root activity continued at a low to moderate level

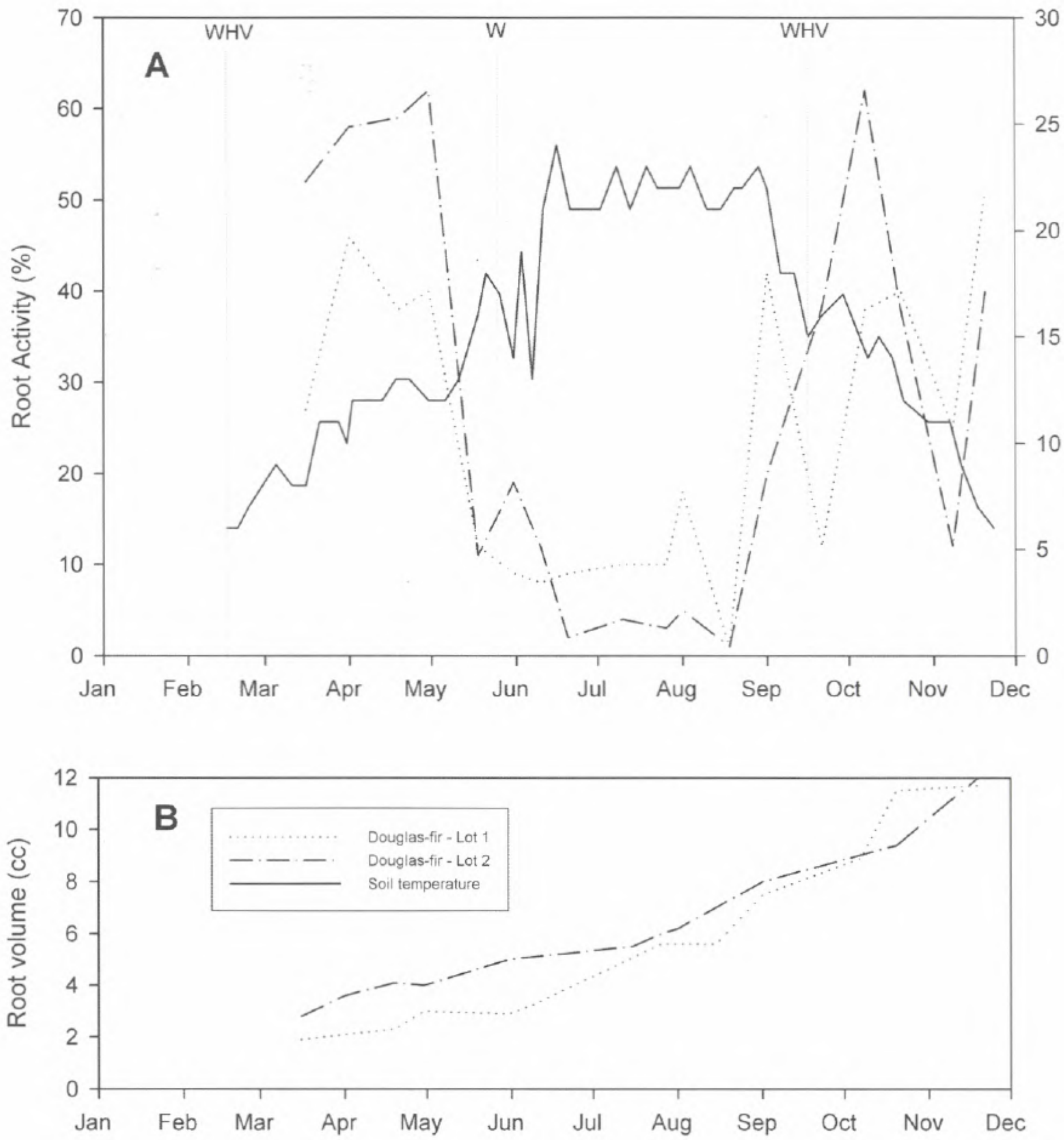

Figure 3—A) Root activity (%) and soil temperatures, and B) changes in root volume for 2+0 Douglas-fir during the course of the 1988 growing season (W = root wrenching; H = horizontal root pruning; V = vertical root pruning).

throughout the summer, with a peak in late June/early July. Activity increased in early September when soil temperatures dropped below 18 °C (64 °F), with a peak in mid-September (figure 4). Root volume showed little to no increase throughout the early part of the growing season, with a sharp increase beginning in early to mid-July. This rate of root volume growth continued through summer and into fall.

Soil Amendments

Soil management created the greatest challenge in the early years at Stone Nursery. Soils had been under agricultural crop production for over 75 years and the intensive cropping left many of the fields in a highly compacted condition and low in soil organic matter. Bulk density samples taken in 1984 were high, averaging 1.54 g/cm^3 and ranging from 1.4 to 1.8 g/cm^3. The nursery targeted 50 percent porosity for bareroot production, but average porosity was calculated at 43 percent, with a range of 34 to 49 percent. In addition, it was common to encounter an impenetrable layer 8 to 13 cm (3 to 5 in) below the soil surface once soils had dried in late spring. Soil tillage practices aimed at shattering this layer, such as ripping and plowing, only created fields full of large clods.

Over the years, Stone Nursery attempted to improve soil tilth by a variety of soil tillage practices, including multiple

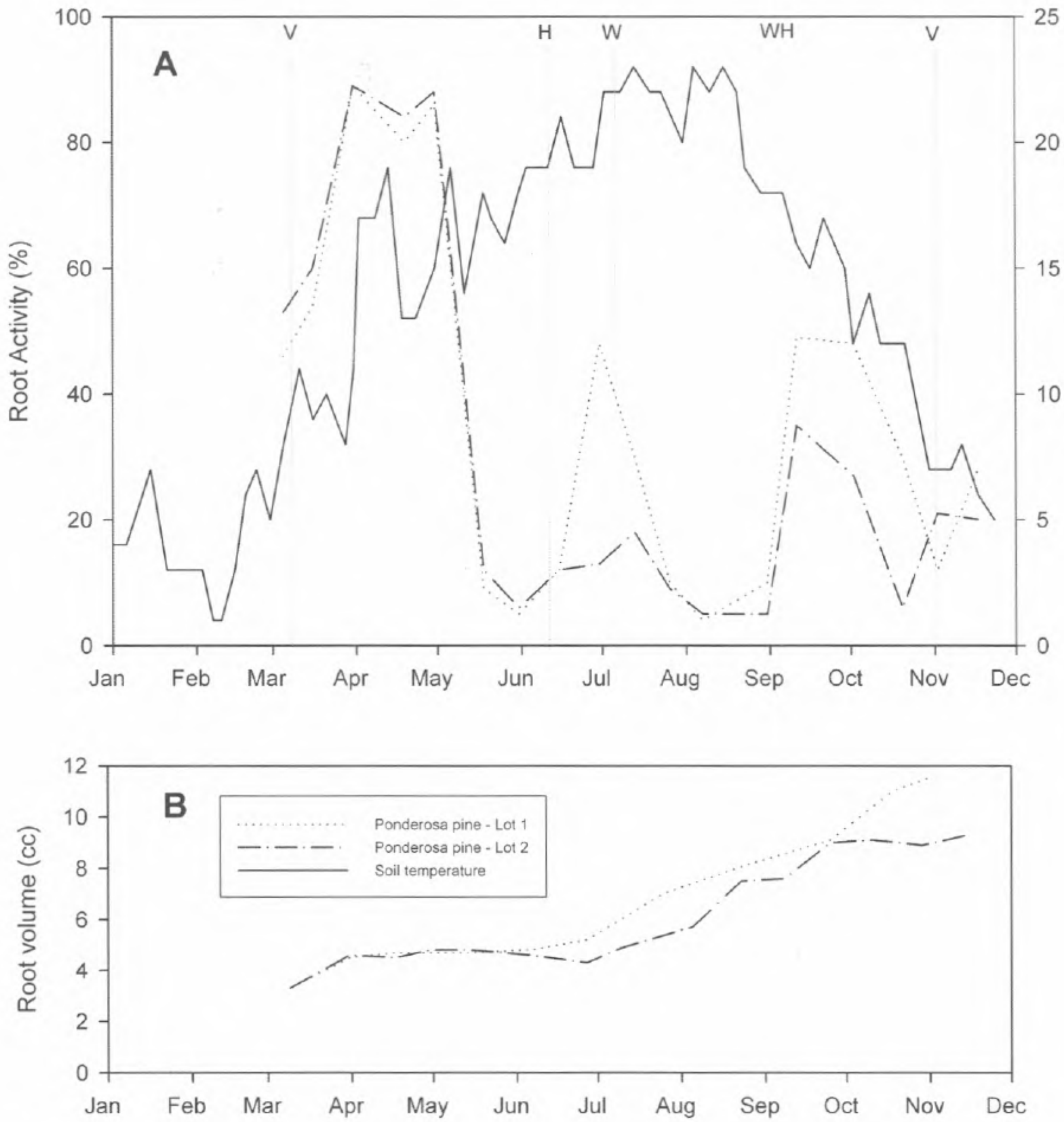

Figure 4—A) Root activity (%) and soil temperatures, and B) changes in root volume for 2+0 ponderosa pine during the course of the 1989 growing season (W = root wrenching; H = horizontal root pruning; V = vertical root pruning).

deep subsoiling operations prior to sowing, multiple soil wrenchings following sowing, and the periodic incorporation of organic matter. Traditionally, fresh sawdust, incorporated into the soil during the fallow period between lifting of one crop and sowing of the next crop, was the preferred organic amendment. It could last for years in the soil, adding a larger and lighter component to the soil, reducing bulk density and soil strength, and avoiding the salt buildup and other contaminants of aged sawdust. The rising costs of the material and the nitrogen necessary for nutrient replacement during decomposition, however, contributed to the need to explore alternative soil amendments for seedling culture. Several amendments were tested to determine their effects on soil nutrient status, soil bulk density, and seedling morphology, including varying volumes of #6 grade pumice, which was expensive but a possible long term solution, and decomposed yard waste/sawdust mix, which was available locally at very low cost.

We observed no significant differences in bulk density or nutrient status between amendment types, even though the specific gravity of pumice is much lighter than the native soil. Although seedlings grown in soil amended with pumice showed an increase in height, there were no significant differences in root morphology and stem diameter. It appeared that standard wrenching practices, applied equally across all treatments, had more effect on bulk density and root growth than the addition of alternative soil amendments.

Timing of Sowing

One goal of the nursery is production of 1 + 0 seedlings that approach the size and have the survival potential of 2 + 0 seedlings. Prior to 1990, the target sowing date at Stone Nursery was the second week of April. Depending on the amount of seeds to be sown and weather conditions, sowing was often not completed until the middle of May. While sowing during this period produced good results, we believed that an earlier sowing date could result in several improvements. First, the longer growing season should produce larger 1 + 0 seedlings. Second, seedlings should be much larger in June and early July, and therefore more capable of withstanding *Fusarium* spp. root disease that often occurs during this period.

In order to determine if seeds sown in late winter (mid-February) could produce larger seedlings and greater seedbed survival than those sown for normal spring production, seedlots of ponderosa pine, lodgepole pine *(Pinus contorta),* Jeffrey pine *(P. jeffreyi),* and incense cedar *(Calocedrus decurrens)* were sown in late winter and again in mid-spring. Seeds were sown at standard nursery sowing densities (195 to 215 seedlings/m^2 [18 to 20 seedlings/ft^2]), cultured under standard nursery culturing regimes for 1 + 0 stocktypes, lifted in late fall, and assessed for stem diameter, height, and root volume.

Seedlings sown in late winter were larger in height and stem diameter for all species. The effect of sowing date on root volume was variable between species and among seedling lots. Significantly larger root volumes were found in incense cedar and ponderosa pine sown in late winter; root volumes for lodgepole pine and Jeffrey pine were not significantly different between sowing dates. There were no differences in survival between sowing dates.

Seedbed Density

Target sowing densities for 1 + 0 stocktypes at Stone Nursery prior to 1990 were traditionally 214 to 236 seedling/m2 (20 to 22 seedlings/ft^2). Densities for 2 + 0 seedlings usually ranged from 236 to 267 seedling/m^2 (22 to 25 seedlings/ft2). These densities were based on practices of other bareroot conifer nurseries in the Pacific Northwest. As production decreased at the nursery, seedbed area became available to grow seedlings at lower densities. The nursery installed several production trials to help determine the optimum seedbed density for various stocktypes and species.

1 + 0 Ponderosa Pine—Ponderosa pine seedlots, for 1 + 0 stocktypes, were sown at three densities in early spring: 107, 161, and 214 (control) seedlings/m^2 (10, 15, 20 seedlings/ft2). Seedlings were cultured under standard nursery practices for 1 + 0 stock, lifted in late fall, and measured for stem diameter, height, root volume (Rose and others 1991), and percentage of seedlings culled—that is, those seedlings that did not meet target specifications or were mechanically damaged during the lifting process. Lowering seedbed density significantly increased seedling stem diameter and root volume, although the highest rate of mechanical damage occurred at the lowest density. There was no significant effect on seedling height.

2 + **0 Ponderosa Pine and Douglas-fir—Density and Root Pruning—Two** trials were established to determine the effects of both sowing density and root culturing on survival and growth of 2 + 0 Douglas-fir and ponderosa pine. In the first trial, treatments included: 1) 214 seedlings/m2 (20 seedlings/ft^2) seedling density and horizontal root prune at 18 cm (7 in) in mid-September (standard nursery practice; control); 2) 130 to 150 seedlings/m^2 (12 to 14 seedlings/ft2) sowing density and 18 cm (7 in) horizontal root prune in mid-September; 3) 130 to 150 seedlings/m^2 sowing density and 10 cm (4 in) root prune in mid-August. Seedlings were lifted in mid-winter and assessed for height, stem diameter, root area, and shoot area with Machine Vision Seedling Inspection Station® equipment (Davis and Scholtes 1995).

We found no significant differences in seedling height, stem diameter, shoot area, and root area between seedbed density treatments in Douglas-fir. In contrast, the ponderosa pine showed significantly greater root area, shoot area, and stem diameter in the low density treatments as compared to the standard treatment. There were no differences between root pruning treatments.

Seedbed densities for the second trial were 107, 161, and 214 (control) seedlings/m^2 (10, 15, and 20 seedlings/ft2). Each density treatment received two different horizontal pruning treatments: 1) horizontal root prune in mid summer (July) at 10 cm (4 in); or 2) root prune in late-summer (August) at 15 cm (6 in). Seedlings were also lifted in mid-winter and height, stem diameter, root area, and shoot area were assessed with Machine Vision Seedling Inspection Station® equipment.

Results of the second trial differed from the first in that the greatest treatment differences were in the seedbed density treatments for Douglas-fir. Root area and stem diameter increased significantly with lower seedbed density. Root pruning treatments yielded no significant differences in Douglas-fir seedling morphology, although the short root prune in mid-July killed 15 to 25 percent of the seedlings within a week of the pruning operation. The ponderosa pine seedlings had significantly larger stem diameters with reduced seedling density, but root area was significantly larger only at a density of 107 seedlings/m^2 with the early root prune treatment.

Root Culturing

In an effort to create a seedling with a more fibrous root system that is easier to pull from the ground during lifting operations and easier to root prune in the packing operations, horizontal root pruning of 2 + 0 seedlings has been done in the fall of the first growing season at a soil depth between 15 and 20 cm (6 and 8 in). Without horizontal root pruning or wrenching, taproots can grow several feet deep, making lifting very difficult. Unpruned seedlings are also difficult to prune in packing operations; taproots at 20 and 30 cm (8 and 12 in) from the cotyledon scar often have stem diameters between 3 and 6 mm. Not only is this hard on employees pruning the roots during packing, the operation leaves the seedling with a large wound.

Several production trials were established at Stone Nursery to determine if root mass could be increased by pruning earlier in the summer and at a shorter depth than the standard practice of 15 to 20 cm (6 to 8 in). The results of two trials have been discussed above. Pruning treatments alone were evaluated on 2 + 0 ponderosa pine and Douglas-fir seedlings during the summer of the second growing season. Treatments were: 1) horizontal prune at 10 cm (4 in) in early August, followed by a 15 cm (6 in) prune in mid-September; 2) horizontal prune at 10 cm in early August only; and 3) horizontal prune at 15 cm in mid-September only (standard practice). Seedlings were lifted in winter, and height, stem diameter, root area, and shoot area were measured with Machine Vision Seedling Inspection Station® equipment. No differences were found between treatments for any morphological characteristics measured.

Timing of Transplanting

Operational transplanting has taken place at the nursery, between March and early June. Due to the hot, dry climate at Stone Nursery, fall transplanting has had a low success rate. Spring transplanting, however, presents other problems. Soil moisture conditions during this period can often be very high (between field capacity and saturation), which makes proper soil preparation difficult. Transplanting under these conditions creates soils with high bulk densities and low macropore spaces immediately around the transplanted roots. The result is seedlings with poorly developed root systems. Waiting for soils to dry and become workable is the best option; however, during some years, not many days like this occur in spring.

The nursery recently re-examined fall transplanting to take advantage of drier and more workable soils, to redistribute a portion of the workload into a slower season, and to possibly increase overall seedling size as compared to those seedlings transplanted in the spring. Douglas-fir, western hemlock *(Tsuga heterophylla),* western redcedar *(Thuja plicata),* and sugar pine *(Pinus lambertiana)* seeds were sown in containers in spring and grown under greenhouse conditions. Seedlings for fall transplanting were extracted from containers and transplanted immediately into fumigated beds; seedlings for spring transplanting were hardened-off, extracted in mid-winter, freezer-stored, and transplanted in mid-spring. Seedlings from both transplanting seasons were cultured for the remainder of the year under standard nursery practices for transplants. All seedlings were lifted in winter of the following year and measured for stem diameter, height, shoot area, and root area measurements using Machine Vision Seedling Inspection Station® equipment.

Although height and stem diameter showed no significant differences among species between transplant seasons, fall transplanted seedlings produced larger root systems than those held over and transplanted in spring (Steinfeld and others 2002). There were no differences in survival for either the spring or fall transplants.

One-Year Stocktype Trials

Throughout the history of the nursery, a number of seedling stocktypes from a variety of locations and breeding zones have been grown. Traditional stocktypes have included: 1) Douglas-fir, ponderosa pine, lodgepole pine, Jeffrey pine, western larch, incense cedar, and several true firs *(Abies* spp.) for 1 + 0 stock; 2) Douglas-fir, ponderosa pine, lodgepole pine, Jeffrey pine, sugar pine, western white pine *(Pinus monticola),* incense cedar, western redcedar, western hemlock, Engelmann spruce *(Picea engelmannii,* and several true firs for 2 + 0 stock; 3) Pacific silver fir *(Abies amabilis)* for 3 + 0 stock; and 4) Douglas-fir and ponderosa pine for 1 + 1 stock.

With the uncertainty of wildfires, site preparation, and budget projections impacting planning and timing of outplanting, Stone Nursery felt that producing a well balanced, miniplug transplant in 1 year would be of great interest to many clients. In an effort to compare the traditional 1 + 0 stocktype with the development of seedlings produced with this newer plug technology, three Douglas-fir stocktypes were tested: 1) 1 + 0; 2) miniplug + 1 (Jiffy-Pots ™ [28mm in length]); and 3) miniplug + 1 (Styroblock™ 2A containers-40 cm^3 [2.4 in^3]). Seeds were sown in JiffyPots™ and Styroblock™ containers in late winter and grown under greenhouse conditions. Seeds for 1 + 0 seedlings were field-sown in mid-spring. Seedlings produced in Jiffy-PotsTM were transplanted in mid-spring, as the roots and medium were held together with netting. Seedlings in Styroblock™ 2A containers were held for transplanting until early summer in order to develop a root system that would hold the medium together during seedling extraction. All seedlings were grown for 9 months, lifted the following winter, and measured for height, stem diameter, root area, and shoot area using Machine Vision Seedling Inspection Station® equipment. The resulting miniplug + 1 seedlings from both container types had greater root area and stem diameter, and lower shoot-to-root ratios, than seedlings grown under standard 1 + 0 stocktype culture.

Management Implications

The nursery trials conducted over the past two decades have allowed the nursery to refine cultural practices based on the physiological responses of the species to local site conditions and different culturing techniques. In the mid-1980s, the nursery changed its philosophy about summer irrigation. Instead of allowing soils to remain dry throughout the summer, the soil profile was irrigated to 30 cm (12 in) when pre-dawn plant moisture stress approached –1.2 MPa (-12 atm). Nursery personnel believed that root volume growth occurred in summer and fall and that moisture during these periods was critical for developing a good root system. Root activity monitoring initiated 3 years after this change supported this decision, as this was the time of year when seedlings were putting on some of their greatest growth. Because high rates of irrigation in summer created a problem of shoot growth exceeding target height specifications, it became common practice to root wrench after most soil profile irrigations. Wrenching created a slight seedling stress, causing slowing of top growth or, if seedlings had set a bud, to prevent budbreak. In addition, the results of root monitoring helped the nursery schedule the timing of second-year nitrogen applications; fertilization now occurs during the peak root activity period in early spring to maximize nutrient uptake.

Soil management practices at the nursery have remained unchanged, with fresh sawdust remaining the amendment of choice. Although many of the standard culturing practices employed at the nursery overwhelm the short-term benefits of applying a soil amendment, these amendments, especially organic amendments, are important. Pumice would possibly provide a long-term benefit, but sawdust or some form of organic matter remains necessary to maintain or raise the organic matter of the nursery soil. The locally available mulch was simply too variable. Since this trial, the nursery has approached the application of a new soil amendment from a short- and long-term standpoint. Any negative effects of the amendment on seedling growth in the first year after application, and the effects on long-term soil productivity, must be determined.

Timing of sowing has changed. Sowing is now done as early in March as possible, during breaks in the weather, when soils become dry enough to form seedbeds. Germinants from early sown seedbeds usually emerge by late March through early April. Although there is a risk of frost damage from low temperatures during this period, frost protection has not been necessary since sowing dates were moved into the late winter.

Seedbed densities of all 1 + 0 species have been lowered from 236 to 161 seedlings/m^2 (22 to 15 seedlings/ft^2). The standard 2 + 0 sowing density of 236 to 267 seedlings/m^2 (22 to 25 seedlings/ft^2) has been reduced to 194 seedlings/m^2 (18 seedlings/ft^2). Economics play a large role in determining optimal seedbed densities for any particular stocktype. More land under production equates to increased hours of tractor operation, increased labor costs, and increased weed control costs. A balance must be found between these costs and the increases in revenue from higher numbers of shippable seedlings. The nursery is considering reducing densities in 2 + 0 stocktypes further, but needs to determine if the benefits outweigh the increased costs associated with placing more land in production.

Little gain, and far more risk, has been found in either shortening the depth of the horizontal root prune or pruning earlier in the summer of the 1 + 0 year. Pruning earlier at a shorter depth increases the risk of seedling mortality and stress. Accomplishing a 10-cm (4-in) root prune in the soils at Stone Nursery is actually very difficult due to the tendency to pull the outside row of seedlings to the surface. Future work at the nursery will look at the possibility of accomplishing the root pruning objectives with several summer wrenching operations in the first growing season or eliminating root pruning entirely.

A portion of transplanting has been shifted to fall. Stone Nursery now begins transplanting container seedlings as early as the first week of September to take advantage of the warm September soil temperatures for greater root growth. In the past 6 years, transplanting in the fall has produced a more balanced, larger seedling at reduced costs, while allowing the nursery more flexibility in managing the work force and equipment.

In exploring the possibilities of new stocktypes, the nursery has demonstrated a potential to produce a seedling with a large root mass and well balanced shoot-to-root ratio in 1 year. In 2002, a transplant system was developed to apply these findings operationally. Based around the Q Plug™, which is a plug that holds together independently of root development, a program of growing seedlings for 10 weeks in Q Plugs™ under greenhouse conditions, transplanting into bareroot beds in early spring, growing for 9 months, and lifting during the winter has been established (Steinfeld 2004). New transplant equipment developed for this container allows for exact spacing of seedlings and optimum seedling density control. Economically, this stocktype has lower culling rates and more crop uniformity, resulting in an increase in revenue from higher numbers of shippable seedlings. Morphologically, the result is a well-balanced seedling with a well-developed root system available approximately 1 year following placement of seedling orders.

Acknowledgments

The authors would like to thank USDA Forest Service Region 6, and specifically Fred Zenson, for supporting the nursery trials program. We would also like to thank the following people at J. Herbert Stone Nursery for their ideas, involvement, and participation in these trials over the years: John Scholtes, David Davis, Mike Minton, Debi Wright, Jerry Mallams, and many others at Stone Nursery who have worked with us. In addition, we would like to thank Mike Amaranthus and Robin Rose for assistance in design and data analysis and Tom Landis and Don Boyer for reviewing this paper.

An extended version of this paper, including more detailed methods and materials, has been published previously (Riley LE, Steinfeld D. 2005. Effects of bareroot nursery practices on tree seedling root development: an evolution of cultural practices at J. Herbert Stone Nursery. New Forests 30:107-126).

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