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Survival and Growth of Planted Alaska-cedar Seedlings in Southeast Alaska

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Seedlings of Alaska-cedar (Chamaecyparis nootkatensis *(D. Don.) Spach) were planted on Etolin Island in southeast Alaska and measured annually for 5 years to evaluate their survival and growth on different types of sites and microsites. Seedling survival and growth were best where light exposure and soil drainage were adequate b ut were poor in heavy shade or soils with impeded drainage. Burned and unburned clear-cut sites supported the best survival, height growth, and diameter growth among site types. Shoot blight, caused by the fungus* Apostrasseria *sp., was common on sites where natural vegetative reproduction of Alaska-cedar was present nearby. Grazing by deer was common on some site types, but deer only consumed new growth and few seedlings were killed. Results illustrate that Alaska-cedar seedlings planted on productive sites may have good survival and early growth.* Tree Planters' Notes 43(3):60-66:1992.

Alaska-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach) has outstanding wood characteristics (Harris 1990) and is consistently the most valuable wood grown in Alaska. Its natural distribution spans from Prince William Sound in Alaska to Northern California (figure 1). The species is known locally as yellow-cedar or yellow-cypress in British Columbia and Alaska because of the bright yellow color of its heartwood. Some wood is used domestically in these regions but most of the harvested volume is exported to Japan, where it is used as a substitute for the native hinoki-cedar (*C. obtusa* (Siebold and Zaccurini) Endlicher), which is in short supply there. In Alaska, the wood and bark of Alaska-cedar was an integral part of traditional Alaska Native culture (Hennon 1992a).

A large-scale forest decline has caused concentrated mortality on at least 200,000 hectares (500,000 acres) (USDA Forest Service 1992) in southeast Alaska since about 1880 (Hennon et al. 1990b). Alaska-cedar is the principal victim in this decline, which is concentrated on sites with poor and moderately poor drainage (Hennon et al. 1990a). The primary cause of this decline is not known, but all recent research indicates that it is naturally occurring and not caused by any contagious biological agent (Hennon 1990, Hennon et al. 1990c). In fact, the decline has apparently not spread to any new sites since its onset more than 100 years ago (Hennon et al. 1990a, b). Thus, the mortality factor, even though still unknown, will not threaten plantations of this valuable species on sites where decline does not now occur.

Despite the great value of Alaska-cedar, little is known about its regeneration requirements in Alaska. The species reproduces naturally on wet sites by vegetative layering (Hennon et al. 1992) but generally does not reproduce prolifically by seed. Forests with a large Alaska-cedar component that are clear-cut in southeast Alaska frequently regenerate naturally to western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce *(Picea sitchensis* (Bong.) Carr.) with regeneration of Alaska-cedar often being minimal or absent (Hennon 1992a).

Thus, losses of Alaska-cedar population due to forest decline and timber harvesting do not appear to be offset by natural regeneration in many areas. For reasons including biodiversity and commercial value, the planting of Alaska-cedar or some silvicultural method for attaining natural regeneration will be needed to replace these losses. Information on regeneration of Alaska-cedar is needed as harvesting becomes more common on sites with moderately poor drainage; frequently these are sites where Alaska-cedar is abundant. The objectives of this study are to perform a preliminary evaluation of general site requirements for planted seedlings of Alaska-cedar and to determine biotic factors that may limit their survival and growth in southeast Alaska. This is the first known planting study of Alaska-cedar seedlings in Alaska.

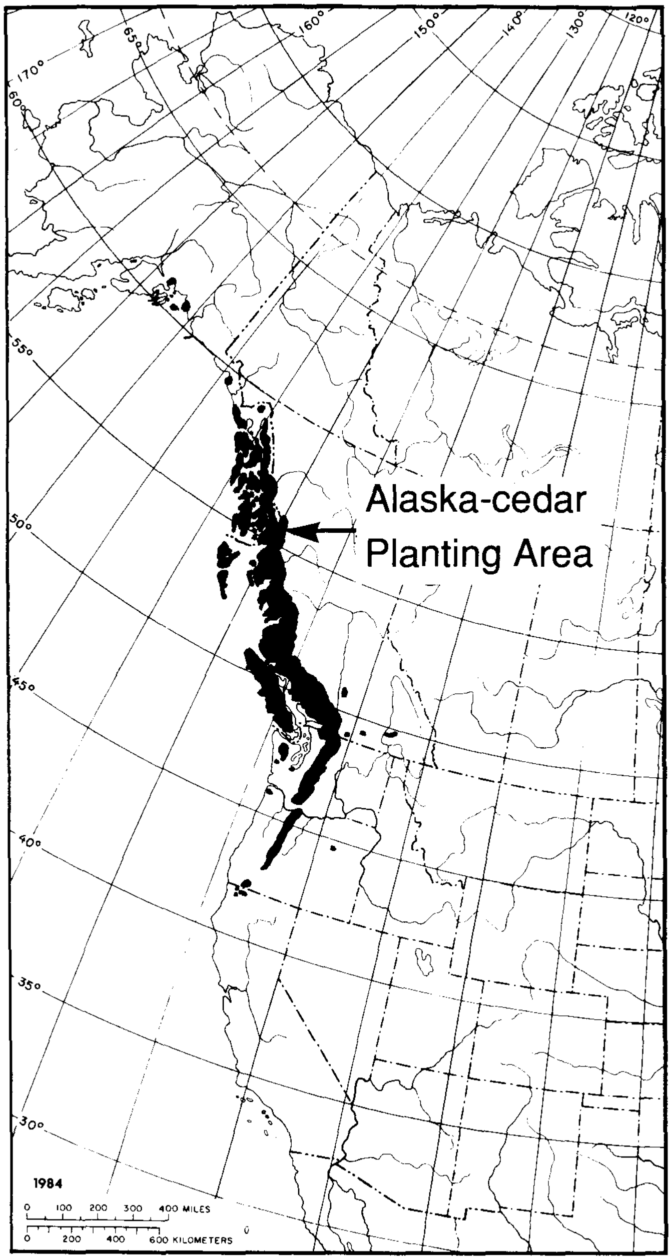

Figure 1—*Natural range of Alaska-cedar (modified from Harris (1990)); the planting site at Anita Bay, Etolin Island, Alaska is noted.*

Materials and Methods

Study location and seedlings. Seedlings were planted at 16 locations near Anita Bay at about latitude 56° N on Etolin Island in southeast Alaska (figure 1). All locations were below 150 m (500 feet) elevation and on slopes less than 20%. Seedlings were planted using hoedad tools during several days of warm, dry weather in June 1986. A numbered aluminum tag attached to a stake flag was placed in the ground adjacent to each seedling for relocation.

All Alaska-cedar seedlings used in this study were grown at the USDA Forest Service nursery in Petersburg, Alaska. Seeds for the seedlings were various, mixed collections from trees on Mitkof and adjacent islands, all within about 80 km (50 miles) of the eventual planting location. Seedlings were grown in Styrofoam cell containers in the greenhouse for 2 years before planting. Seedlings averaged 40.8 ± 0.19 cm and 4.0 ± 0.03 mm (means ± standard errors) in height and diameter, respectively, at the time of planting.

Study design. A total of 800 seedlings of Alaska-cedar were planted, 50 seedlings at each of 16 sites. At each site, seedlings were planted in 5 rows of 10 seedlings. Spacing was 4 m (13 feet) within and between rows. Seedlings were not fertilized or protected from deer. Each planting site represented one of the following conditions:

1. Open bog
2. Low-volume (scrub) stand of Alaska-cedar
3. A stand similar to the low-volume stand (#2) that had recently been clear-cut
4. High-volume, productive stand that was uncut (heavily shaded under canopy)
5. High-volume productive stand that was cut and not burned
6. High-volume productive stand that was cut and burned

Table 1—*General conditions of soil moisture drainage and exposure to light at each type of planting site*

Site type	No. sites	No. seedlings	Exposure to light	Soil moisture drainage
1. Bog	2	100	Exposed	Wet
2. Scrub, uncut	4	200	Moderately shaded	Moderately wet
3. Scrub, cut	2	100	Exposed	Moderately wet
4. Productive–uncut (dark)	2	100	Shaded	Drained
5. Productive–cut–unburned	2	200	Exposed	Drained
6. Productive–cut–burned	4	100	Exposed	Drained
Totals	16	800		

Each site had some combination of poor, moderate, or good soil drainage and poor, moderate, or good exposure to light. For example, bogs generally had poor drainage and good light exposure. Light exposure and soil drainage were noted for the specific planting location as each seedling was planted. The physical appearance of the planting substrate for each seedling was examined during planting and classified as abundant rotten wood, disturbed soil (mineral soil exposed), adjacent to a stump, or undisturbed duff. A similar classification was used previously (Sidle and Shaw 1983) in describing planting microsites of clear-cuts in southeast Alaska (table 1).

Measurements. The height and basal diameter were measured for each seedling at planting in 1986 and then measured before the initiation of shoot growth each spring through 1991. Seedling height (to the top of the straightened leader) and basal diameter (at the groundline) were measured to the nearest centimeter and millimeter, respectively. Shoot blight caused by the fungus *Apostrasseria* sp. (Hennon 1992b) and browsing by deer were also noted annually for each seedling. The color of each seedling was classified each year as green (> 91% green), green-brown (51 to 90% green), brown-green (1 to 50% green), or brown (0% green). Seedlings were judged to be surviving in 1991 if they were green or green-brown.

Because of the exploratory nature of this study and the unbalanced design, statistical analyses are not reported. Rather, data on seedling survival, height growth, diameter growth, and the incidence of grazing and shoot blight are grouped by site type and means are presented graphically.

Results

Planting sites. Exposure to light varied for seedlings planted in the scrub-uncut type, where the canopy was somewhat open and the density of brush was variable; however, exposure was more uniform at all other site types. Excessively wet soils were noted when free water was observed during planting; bog vegetation or skunk cabbage were typical of these wet microsites. Soil drainage appeared relatively consistent at a few sites (for example, poor drainage for all seedlings planted in bogs) but was variable at most other sites. Even the three productive site types had some poorly drained soils (average 6% of planting microsites).

In the clear-cut site types, the undisturbed duff was the most common soil type (61% of planting microsites), followed by almost equal frequencies of close proximity to stumps, rotten wood, and disturbed duff. Almost all planting microsites were recorded as undisturbed duff at other site types. Although vegetation and some fine woody slash were destroyed in the burned units, burning was light and duff layers generally remained intact.

Seedling survival. One year after planting, seedling survival in all site types approached 100%, except for the 81% survival in bogs (figure 2). By 1991, however, seedling survival was markedly affected by site type. Seedlings in bogs continued to die in successive years after planting, leaving only 23% of the seedlings alive in 1991. Most of these surviving seedlings in bogs occurred on slightly raised areas (hummocks), but even these seedlings were off-color.

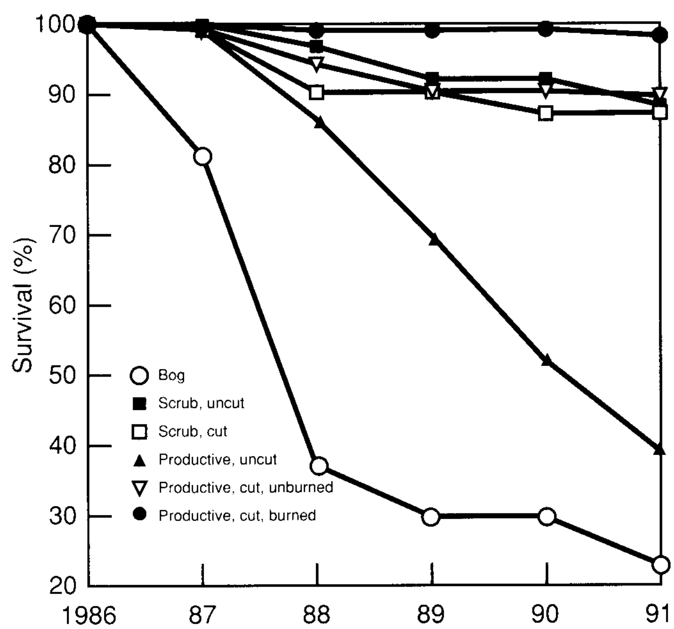

Figure 2—*Survival of Alaska-cedar seedlings in six site types from the time of planting in 1986 to 1991. See table 1 for a description of each site type.*

Seedlings in the productive-uncut (heavy canopy) type appeared healthy 1 year after planting (98% were green) but many seedlings appeared brown and began to die within 2 years. Only 39% were alive in 1991 and many of these had dead shoots and dead terminal leaders.

Survival after 5 years in the field was greater than 88% in all other site types. Many seedlings that died on these sites were planted in wet, poorly drained microsites. The productive-cut-burned site type had the best rate of survival (97%).

Growth. Both height and diameter growth of seedlings were influenced by site type (figures 3

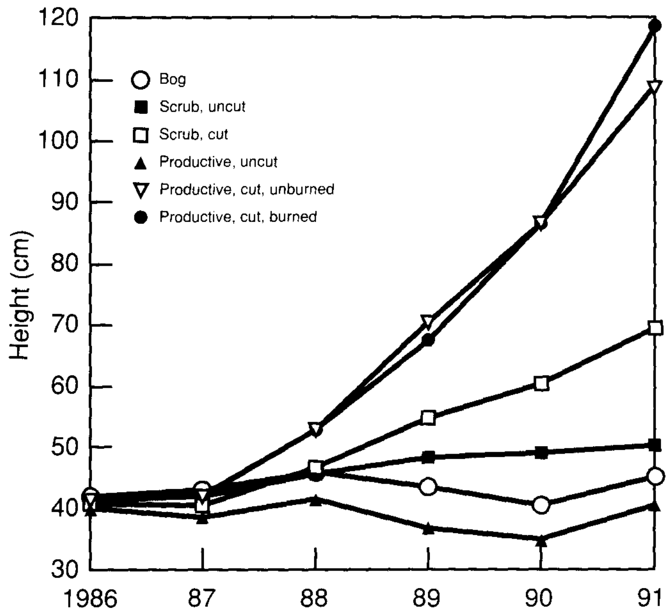

Figure 3—*Mean height growth of Alaska-cedar seedlings planted in six different site types.*

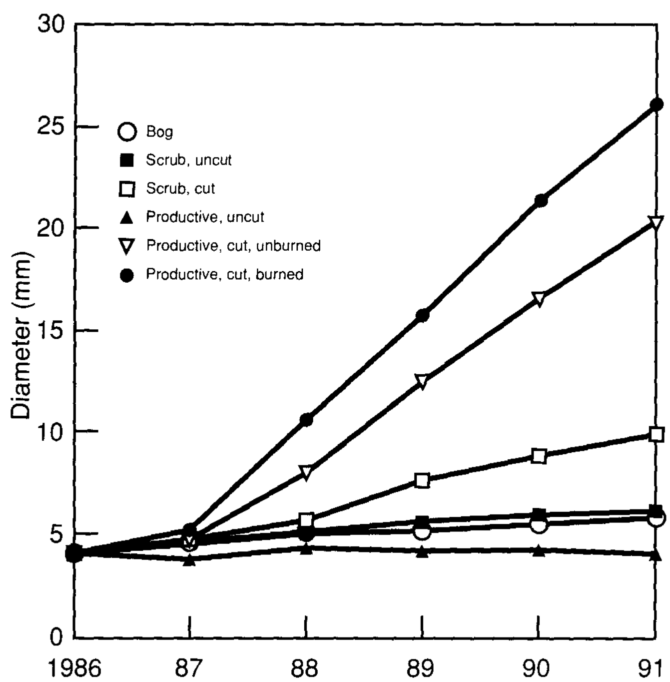

Figure 4—*Mean basal diameter growth of Alaska-cedar seedlings planted in six different site types.*

and 4). Height and diameter results presented here include only those seedlings that were alive at each annual measurement. Heights of seedlings 1 year after planting (in 1987) exhibited little growth and were similar among different site types (figure 3). By 2 years after planting (1988), however, seedlings in the burned and unburned productive clear-cut sites began rapid growth. This trend continued through 1991 with annual height growth and final heights being greatest for seedlings in the two productive-cut site types, followed by the scrub-cut type. Thus, seedling height growth was greatest in the three site types that had been harvested and had maximum light exposure. Heights of seedlings in other site types acquired only modest gains (scrub-uncut type) or some actually lost height (for example, bog and productive-uncut (dark) types). Seedlings in the latter two types frequently had dead tops, which accounted for their reduced heights.

Diameter growth of live seedlings followed the same trend as height growth (figure 4). Seedling diameters increased slightly in all site types (except the dark sites) the first year. From the second year (1988) through the fifth year (1991), seedling diameter increased rapidly in the three clear-cut site types (burned, unburned, and scrub), although seedlings in the scrub-cut type did not keep pace with those in the other two types. Seedlings in the bog, scrub-uncut, and productive-uncut site types produced little diameter growth after the second year. The largest Alaska-cedar, 5 years after planting, was 229 cm (7.5 feet) tall with a 59-mm (2.3-inches) basal diameter. This seedling/ sapling was growing an average of 37 cm in height and 11 mm in diameter per year.

The productive-cut-unburned site type was represented by four locations, two of which were planted less than a year after harvest and two planted 2 to 3 years after harvest. Thus, the final mean height and diameter of seedlings can be distinguished as those "planted early" and "planted late" and compared to growth in burned-cut and scrub-cut sites. Seedlings planted late had smaller heights and diameters than those planted early but were larger than seedlings planted in the scrub-cut type (figure 5). For seedlings planted quickly after clear-cutting on productive sites, growth did not appear to differ on burned and unburned sites.

Soil type did not have a noticeable effect on height or diameter growth of seedlings, except that both heights and diameters tended to be smallest among seedlings planted in the rotten wood type. Frost heaving of seedlings was not a problem in disturbed soils nor did it occur in any soil type in this study.

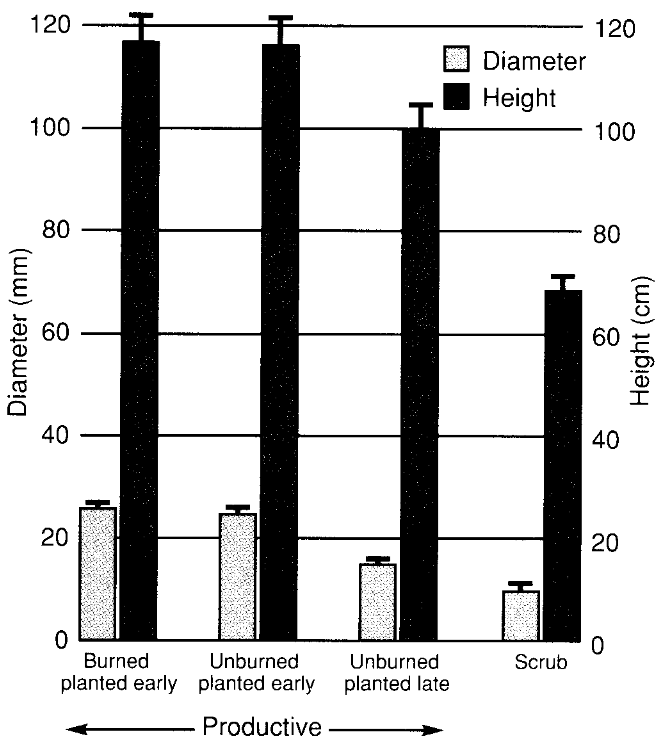

Figure 5—*Height and diameter of Alaska-cedar seedlings 5 years after planting on four harvested site types: 1. productive, burned, planted early; 2. productive, unburned, planted early; 3. productive, unburned, planted late; and 4. scrub, planted early. Values are means ± one standard error.*

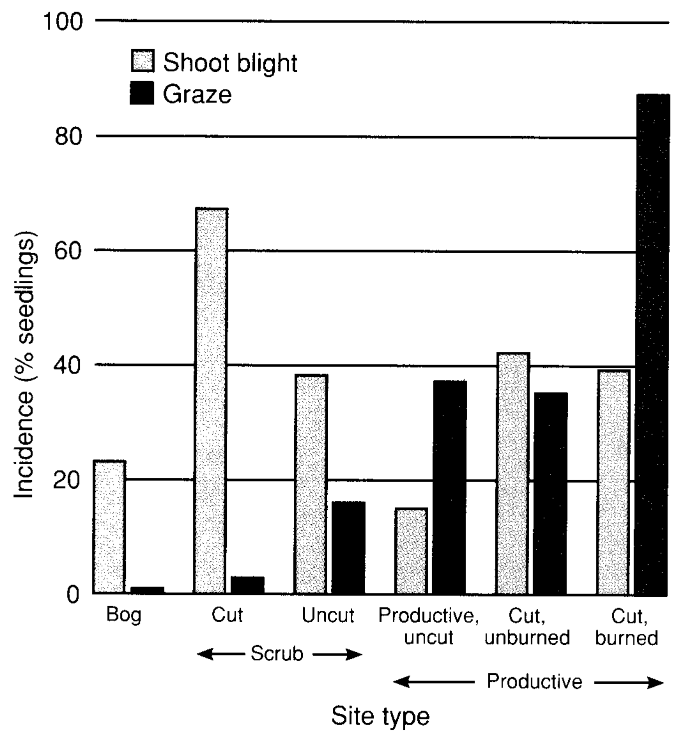

Figure 6—*Percentage of live Alaska-cedar seedlings grazed by deer or infected with shoot blight fungus* (Apostrasseria *sp.) on six different site types.*

Grazing. The incidence of grazing by deer was affected by site type; it was uncommon on seedlings in bog, scrub-uncut, and scrub-cut site types (figure 6). Grazing was more frequent on the three productive site types and reached the highest level (87%) on the cut-burned sites. Repeatedly grazed seedlings in clear-cuts frequently had bushy crowns and noticeably large diameters; however, grazing generally did not produce differences in seedling height or diameter. Ungrazed seedlings tended to be taller in the productive burned and productive uncut site types than grazed seedlings in the same site types. Grazed seedlings in productive-cut-unburned and scrub-cut site types tended to have larger diameters than ungrazed seedlings in the same site types, particularly in the former plots where average seedling diameter was 17 and 26 mm for ungrazed and grazed seedlings in 1991, respectively.

Shoot blight. Seedlings infected with *Apostrasseria* sp. had one or more dead or dying (yellow) shoots. Terminal leaders were attacked on some seedlings every year. Shoots typically died back less than 15 cm from branch tips, but three large seedlings were apparently killed by the fungus. Black fruiting bodies (acervuli) of *Apostrasseria* sp. were usually evident after tissues had been killed. Fruiting bodies of other fungi, such as *Herpotrichia juniperi* (Duby) Petr., were also frequently observed on these symptomatic tissues.

The incidence of shoot blight was associated with site type (figure 6) with the greatest incidence (67% of seedlings by 1991) occurring on seedlings in the scrub-cut site type. The productive-uncut type had the lowest incidence of shoot blight (15% of seedlings). Microsite features, such as drainage and light exposure, had no apparent effect on the incidence of shoot blight. Shoot blight had no measurable effect on height or diameter growth of seedlings.

One year after planting, numerous seedlings in exposed locations had noticeable symptoms somewhat similar to those caused by *Apostrasseria* sp. However, these seedlings lacked the fruiting bodies of the fungus *Apostrasseria* sp. Some 23% of seedlings had a scorched appearance with scattered brownish scales and dead shoot tips in 1987.

Ninety-eight percent of these seedlings occurred in exposed locations. Most scorched seedlings, particularly those on favorable sites and microsites, appeared green after another year.

Discussion

This study illustrates that planted seedlings of Alaska-cedar can successfully be established in southeast Alaska. Results also demonstrate the overwhelming effect that site factors have on survival and growth of seedlings. On sites with good light exposure and soil drainage, planted seedlings of Alaska-cedar are capable of excellent survival and growth. Survival and growth are particularly good on productive clear-cut sites where light and soil factors may be optimal and competition from other vegetation is reduced by early planting or burning.

Seedling survival and growth were diminished by heavy shade and poor soil drainage. Although Alaska-cedar has sometimes been considered to be shade tolerant, this feature of its reproduction has never been studied adequately. Results from this preliminary study suggest that planted seedlings cannot tolerate heavy shade. In a separate study, the fate of several hundred young (1- to 2-year-old), naturally regenerated seedlings of Alaska-cedar at three sites near Peril Strait, Alaska, was followed for several years (Hennon unpublished data). These small seedlings occurred in high-volume stands of mature Alaska-cedar and western hemlock with closed canopies and considerable shade. By the third year, over 99% of the seedlings had perished. Most seedlings shriveled and died without apparent attack by pests or by deer feeding, perhaps the result of too little sunlight.

In the present study, the poor survival of Alaska-cedar planted in wet, poorly drained soils may seem surprising. The species is apparently well adapted to growing in these wet soils. Many patches of prostrate, asexually reproducing Alaska-cedar were growing in the bogs where survival of planted seedlings was so poor. Perhaps the nursery-grown seedlings were not adapted to the anaerobic, infertile soil conditions of bogs.

The scorched appearance of seedlings on exposed sites 1 year after planting was probably the result of warm, dry weather that occurred during, and several days after, planting. These seedlings apparently experienced a form of transplant shock due to desiccation. Their good subsequent recovery indicates their responsiveness to adverse conditions when planted on favorable sites.

Biotic factors, such as grazing by deer and infection by *Apostrasseria* sp., usually cause mortality in very young seedlings or in older seedlings that are repeatedly attacked. At its current level, shoot blight is not causing serious damage even in site types where it is common. The incidence of the disease appears to be intensifying at all sites in this study and this trend may continue for several more years. *Apostrasseria* sp. only causes disease on young trees, however, and stands of Alaska-cedar will eventually outgrow susceptibility. In a survey of pathogenic fungi on mature Alaska-cedar, the fungus was not detected (Hennon 1990, Hennon et al. 1990c).

Because only recently grown tissues of seedlings are grazed by deer, most grazing does not result in direct mortality. Terminal and lateral shoots near the tops of seedlings are most frequently grazed, which results in some grazed seedlings that are short and bushy. Grazing of seedlings on productive sites can have the effect of delaying height growth. Diameter growth is sometimes actually enhanced in grazed seedlings (presumably, so is root growth), and seedlings may attempt to resume their shoot/root balance by accelerating height growth in ensuing years. If seedlings go ungrazed for a year or two under good growing conditions, they should attain heights that will not allow deer to feed upon their terminal leaders.

Seedlings planted in areas of dense deer populations may experience intense grazing every year. By their reduced height and photosynthetic area, grazed seedlings will be at a disadvantage with competing vegetation. Such seedlings will probably not survive competition for light and nutrients with species of brush such as *Vaccinium* spp. and western hemlock. Some planted Alaska-cedar seedlings in unburned clear-cuts were grazed in consecutive years and were becoming crowded and even overtopped by hemlock and brush in 1991. This was particularly apparent on sites planted several years after harvest. The combination of deer grazing and competing vegetation may be the greatest threat to survival of Alaska-cedar seedlings on well-drained sites.

Regenerating Alaska-cedar on the most poorly drained sites would present a challenge because nursery-grown seedlings will frequently perish in the mucky soil; however, such sites are not harvested or managed. Planted seedlings in soils with somewhat better drainage (scrub sites) may have good early survival, but their growth will not be rapid. Selection of drier microsites by planters may improve seedling survival and growth. Perhaps the Alaska-cedar that exists as vegetatively-reproducing understory in some scrub stands could be encouraged to grow into trees following some stand treatment, such as salvage or overstory harvest. On wet sites that already exhibit the decline problem, some mortality of regenerated Alaska-cedar should be expected over the life of the regenerated stand. However, forest managers can plant Alaska-cedar on productive sites without fear of decline spreading to the plantation.

Private timber companies in British Columbia perceive a valuable future market for Alaska-cedar as a specialty wood. Approximately 900,000 Alaska-cedars are planted every year on productive sites in coastal British Columbia. "Stecklings," asexually reproduced rooted cuttings, account for most of the planting stock there. In the past several years, the Alaska Region of the USDA Forest Service has initiated efforts to collect seed, produce stock, and plant nursery-grown seedlings of Alaska-cedar on harvested sites. These efforts will offer opportunities to replace Alaska-cedar where it is harvested or to grow it on the many wet sites or productive sites where it is not currently found. In addition, we are exploring methods of attaining adequate natural regeneration through seed tree harvests and soil disturbance.

Uncertainties still remain with techniques of managing stands of Alaska-cedar once they have been established with natural regeneration or planting. Silvicultural information on site selection, spacing, and pruning is needed in both British Columbia and Alaska to determine their effects on wood quality and volume production.

Conclusions

Planting of Alaska-cedar may be needed to attain adequate regeneration of this valuable tree species in southeast Alaska. This study provides preliminary information on planting requirements of Alaska-cedar. Results suggest the following:

1. Seedling survival and growth appear best on sites with good soil drainage and light exposure, but early survival is also good on sites with moderately poor drainage.
2. If significant vegetation competition is expected, site preparation to retard competing vegetation (for example, burning) should be considered and/or sites should be planted promptly after harvest. Burning will likely increase browsing on seedlings if deer are present.
3. To maximize growth, seedlings can be protected (for example, by Vexar) in areas of high deer population.

Acknowledgments

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Propagation of Loblolly, Slash, and Longleaf Pine from Needle Fascicles

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*A method of vegetatively propagating pine from needle fascicles, previously reported in China, was tested for its potential use in propagating loblolly (*Pinus taeda *L.), slash (*P. elliottii *var.* elliottii *Engelm.), and longleaf (*P. palustris *Mill.) pine. The method consists of a 16- to 20-hour auxin treatment, a 30- to 60-day rooting stage, and a 60- to 120-day shooting stage. All stages are completed under greenhouse conditions, the first two in water solutions and the third in potting soil. The results of two experiments are reported here. In experiment 1, four auxins were tested with loblolly and slash pine on two collection dates. Overall, slash pine rooted better than loblolly, but loblolly shooted better. Indole-3-acetic (IAA) and indole-3-butyric (IBA) acids were effective at promoting roots and shoots with both species, while a-naphthaleneacetic (NAA) and indole-3-propionic (IPA) acids were effective at promoting roots with slash pine only. Several treatment combinations produced regeneration rates above 25%. In experiment 2, needle fascicles from loblolly, slash, and longleaf pine stock plants of varying ages (1 to 10 years) were cultured. Rooting declined sharply between ages 1, 2, and 3 for loblolly and slash, with slash rooting better than loblolly and longleaf. Slash and longleaf rooted fascicles produced more shoots than loblolly, although relatively few shoots were formed in this experiment. It appears that this vegetative propagation method has potential for the rapid increase of selected loblolly, slash, and longleaf pine seedlings, and it may have special significance for longleaf pine, since the "grass stage" of this species severely limits the production of standard stem cuttings.* Tree Planter's Notes 43(3):67-71: 1992.

Vegetative propagation of pine seedlings is an important tool in both the production and experimental components of pine genetics and breeding programs. Mass vegetative propagation of selected families is a useful adjunct to improvement programs based on recurrent and non-recurrent selection. Experimentally, statistical efficiency is increased when treatments are applied to clones instead of families, due to the absence of genetic variance within the clones.

Several factors, known and unknown, limit the success of propagation systems for the various species of pine. One of the most problematic factors is the inability to produce large numbers of viable explants in a short time. Several tissue culture techniques hold promise for solving this problem; however, they are costly and require specialized facilities and labor. An alternative method employs the short shoots (that is, needle fascicles or fascicles) of pine as explants in a non-sterile greenhouse propagation system. Because individual pine seedlings produce 30 to 100 needle fascicles in their first year of growth, a successful fascicle culture technique may provide a practical solution to this problem.

The literature contains many reports of needle fascicle culture experiments (Toda 1948, Mergan and Simpson 1964, Rudolph and Neinstaedt 1964, Hare 1965, Wells and Reines 1965, Kummerow 1966, Libby and Conkle 1966, Larson and Dingle 1969, MacDonald and Hoff 1969, Sargento and Barker 1978, Andrews 1980, Struve and Blazich 1984). Most indicate acceptable rooting rates (greater than 50%), though with little or no shoot initiation or elongation. In general, the higher rooting rates have been associated with lower shooting rates, thus, regeneration rates have been very low. Wang and Wei (1988), Wang, Wang, and Chao (1984), and JFRI (1981) summarized needle fascicle culture studies of slash pine conducted in China. Rooting results for 1- and 2-year-old slash pine were consistently high (46 to 95%) and relatively rapid (4 to 5 weeks). Shoot production on rooted fascicles also fell in this range (50 to 80%) at 10 weeks, resulting in 25 to 75% regeneration rates in 14 *to* 15 *weeks.* In terms of regeneration rate and quantity, these results compare favorably with standard stem cutting propagation methods.

To our knowledge, the method developed in China is different than any reported in the U.S. literature. The primary difference is that in China the rooting phase is completed in a water-based medium, instead of a solid medium (such as peat, perlite, sand, etc.). To evaluate the water-based method, we conducted several preliminary experiments with loblolly, slash, and longleaf pine. Here we report the results of two experiments designed to test the effects and interactions of species, auxins, and ages of stock plants on root and shoot initiation.

Materials and Methods

Standard protocol. The propagation method is a modification of that described by Wang and Wei (1988) and Wang, Wang, and Chao (1984). One-year-old needle fascicles were carefully removed from the stock plants. For 1-year-old plants, fascicles located at or just below the median point of the main stem were used. The fascicles were bundled together by tree, and placed in moist, cool sand until all collections for the day were made. Following collection, the bundles were thoroughly rinsed in cold running tap water. The basal 2-mm (approximately) of tissue was then trimmed from each fascicle with a razor. The fascicles were rebundled (consistent with the particular experimental design) and stood upright in a shallow glass pan containing an auxin solution (75 to 150 ppm auxin, pH 5.5). Following 16 to 20 hours in auxin, the bundles were removed, thoroughly rinsed under running tap water and returned to a glass pan containing a nutrient solution (60 ppm H_3B0_3, 40 ppm NH_4N0_3, and 20 ppm thiamine-HCl, adjusted to pH 5.5). Water naturally buffered to pH 6.0 (in these experiments, water from Palmer Creek in Harrison County, Mississippi) was used in both the auxin and nutrient solutions. We have found that both natural and RO (reverse osmosis) water are superior to tap water (unpublished data). The nutrient solution was replaced and the bundles were rinsed one time each week. The level of the nutrient solution (5 to 7 mm) was increased to compensate for evapotranspiration losses as needed (usually 2 or 3 times each week). When roots had emerged and grown approximately 5 to 10 mm, the rooted fascicles were transplanted into a potting mix of forest soil, peat, and vermiculite (2:3:1). All culturing phases-auxin treatment, rooting, and shooting-were completed in a temperature (21 to 29 °C) and relative humidity (75 to 85%) controlled greenhouse under natural photoperiod.

Experiment 1. Seeds from a bulk collection of Livingston Parish (Louisiana) loblolly pine trees (75 total) and an open-pollinated collection of a slash pine clone were sown in the Harrison Experimental Forest (HEF) nursery in April 1990. About 60 vigorous seedlings from each species were selected and transplanted to a separate nursery bed in June 1990. These transplants were spaced approximately 30 x 30 cm. During the last week in August the distal ends of each shoot were cut off in an effort to stimulate fascicle bud and needle development.

Needle fascicles were collected on November 29, 1990 (date 1, N = 540 fascicles) and February 12, 1991 (date 2, N = 900 fascicles) from 30 to 40 trees of each species. The fascicles of each species were grouped at random into bundles of 15. Three bundles on date 1 and 5 bundles on date 2 of each species were treated with 1 of 12 auxin treatments (treatment combinations of IBA, IAA, IPA, and NAA each at 75, 100, and 150 ppm). The treatments were completed during 16 hours, on the day following collection, in a temperature and humidity controlled greenhouse. Following the auxin treatment, the bundles were transferred to the standard nutrient solution (see standard protocol) in the same greenhouse. Nutrient solutions were replaced weekly and the fascicles were inspected for rooting. Fascicles with root(s) approximately 5 mm long were scored as rooted, removed from the bundles and planted into potting media. The transplanted fascicles were further observed and scored for spontaneous shoot initiation (shoot length > 10 mm).

Experiment 2. Loblolly, slash, and longleaf pine stock plants aged 1, 2, 3, 5, 7, and 10 years from seed were located in nursery beds and various field plantings on the HEF. The 1-year-old loblolly and slash explants came from the same material used in experiment 1, while the 1-year-old longleaf explants came from potted wind-pollinated seedlings of several local trees. These seedlings had been grown outdoors, under shadecloth (approximately 33% shade).

Needle fascicles were collected on January 15, 1991, from 3 to 14 (mostly 7) stock plants in each species-age combination. Seven to 15 fascicles were collected from each tree and grouped into 3 to 7 bundles of 15 or 30 fascicles per species-age combination. The bundles were treated in 100 ppm IBA for 16 hours and then cultured according to the standard protocol. Rooting and spontaneous shoot initiation were scored as in experiment 1.

Data Analysis. Two variables were statistically analyzed--rooting in each experiment and shooting in experiment 1-date 1, only. Rooting was scored as the proportion of needle fascicles rooted (less than 90 days), and shooting was scored as the proportion of the rooted fascicles that produced a shoot (less than 210 days).

Analyses of variance (SAS proc GLM, Type III) were computed for each of the three data sets. All effects were considered fixed. Pairwise t-tests (a <.05) were used for treatment mean comparisons when differences were suggested (a < .10) by the F-tests. In experiment 1-date 1, the data were inadvertently pooled (during collection) across replicate bundles within the treatment combinations, thus reducing the model to two factors and their interaction. Since the range in auxin concentration was small (75 to 150 ppm), we chose to analyze the effects of species and auxin, allowing the levels of concentration to serve as replications. The experiment 1-date 2 data were analyzed with the same model, with 15 replications (that is, 5 replicate bundles X 3 concentrations = 15) of 15 fascicles per treatment combination. In experiment 2, a two factor-plus-interaction model was used, with 3 to 7 replications of 15 or 30 fascicles per treatment com bination. Because no fascicles from 10-year-old trees rooted, the number of levels of age was reduced to five (1, 2, 3, 5, and 7 years).

Results

Experiment 1. The percentages of needle fascicles rooting, shooting, and regenerating (that is, rooting X shooting) are presented in table 1. For both species, fascicles from date 1 responded better than did those from date 2. Analysis of variance and F-test results for dates 1 and 2 are presented in table 2.

Date 1. Differences were significant between species and auxins for rooting and between auxins for shooting (table 2). The species X auxin interaction was not significant for rooting or shooting. Slash pine was significantly more responsive to root initiation than was loblolly pine. In contrast, a higher percentage of rooted loblolly pine fascicles produced shoots than did slash pine, although this difference was not significant. IBA and IAA were significantly more effective at promoting roots and shoots than were IPA and NAA. When treated with either IBA or IAA, both species showed similar regeneration percentages, however by different

Table 1—*Summary of rooting (R), shooting (S), and regenerating (P) data for 2 dates of fascicle collection in experiment 1*

Auxin	Date 1 (Nov. 29, 1990)						Date 2 (Feb. 12, 1991)					
	Slash			Loblolly			Slash			Loblolly		
(ppm/mM)	R%	S%	P%	R%	S%	P%	R%	S%	P%	R%	S%	P%
Overall	63	19	12	23	40	9	36	3	1	17	8	1
IAA overall	70	28	19	39	53	21	20	7	1	38	6	2
75/.43	42	53	22	58	58	34	20	0	0	32	8	3
100/.57	100	18	18	38	65	25	35	4	1	65	6	4
150/.86	69	16	11	22	20	4	7	40	3	17	0	0
IBA overall	87	22	19	41	51	21	56	2	1	28	10	3
75/.37	100	27	27	47	38	18	84	0	0	24	11	3
100/.49	91	20	18	18	50	9	35	4	1	44	6	3
150/.74	69	19	13	58	62	36	51	3	1	16	17	3
IPA overall	53	20	10	7	0	0	47	3	1	3	17	1
75/.40	60	22	13	4	0	0	20	0	0	4	0	0
100/.53	36	13	5	13	0	0	63	2	1	3	0	0
150/.79	62	21	13	4	0	0	57	5	3	3	50	2
NAA overall	43	5	2	5	57	3	22	0	0	0	0	0
75/.40	38	0	0	4	0	0	0	0	0	0	0	0
100/.54	69	0	0	12	80	10	27	0	0	0	0	0
150/.81	22	30	7	0	0	0	39	0	0	0	0	0

Notes: R% is percentage of fascicles rooting in 90 days, S% is percentage of rooted fascicles producing a shoot in 210 days, and P% is the product of R% and S%, that is, the percentage of fascicles regenerating whole plants in 210 days. Numbers of needle fascicles treated per species-auxin-concentration treatment combination were 45 for date 1 and 75 for date 2. Levels of auxin concentration were treated as replications in all analyses. Date 1: least significant difference (LSD, $\alpha < .05$) between species for rooting = 16%, LSD's between auxins for rooting = 22% and for shooting = 26% Date 2: LSD's between auxins for slash rooting = 32% and for loblolly rooting = 19%.

Table 2—*Analysis of variance for rooting and shooting data in experiment 1*

Source	Date 1 df	Date 1 Roots MS	Date 1 Shoots MS	Date 2 df	Date 2 Roots MS
Species	1	.954*	.074	1	1.083*
Auxin	3	.217*	.117	3	0.501*
Species × Auxin	3	.007	.063	3	0.513*
Error	16	.034	.045	112	0.054

*Significant at the .01 level of probability.
Notes: Species were loblolly and slash pine. Auxins were IAA, IBA, IPA, and NAA at concentrations of 75, 100, and 150 ppm. MS = mean square, df = degrees of freedom.

means-slash with higher rooting and lower shooting, and loblolly with lower rooting and higher shooting.

Date 2. All sources of variation in rooting were significant (table 2). Slash and IBA produced the highest rooting responses, although the significant species x auxin interaction made interpretation of the main effects difficult. The effect of auxins was analyzed separately for each species (not shown). For slash pine, IBA and IPA were significantly (a < .05) more effective for rooting, while, for loblolly, IAA and IBA were significantly more effective. Shooting rates were not statistically analyzed, but the summarized data showed trends similar to date 1 (table 1). Rooted loblolly fascicles produced a higher percentage of shoots than did those of slash, and IBA was the more effective auxin.

Experiment 2. The percentages of needle fascicles rooting, shooting, and regenerating are presented in table 3. The analysis of variance and F-tests revealed that all sources of variation were significant (table 4). The significant species x age interaction was primarily due to the sustained rooting rate of needle fascicles taken from 2- and 3-year-old longleaf pine stock plants (table 3). It is interesting to note that the 2-year-old longleaf stocks produced higher shooting rates than the land 2-year-old loblolly and slash stocks, although the number of shoots in this experiment was low (34 shoots on 283 rooted fascicles).

Discussion

Our results demonstrate that water-based needle fascicle culture is feasible for propagating loblolly, slash, and longleaf pine seedlings. However, much additional research and development will be required to refine the protocol for practical use in pine genetics and breeding programs. Under the conditions of our experiments, IBA and IAA (75 to 150 ppm) were the superior auxins for root and subsequent shoot initiation and elongation. That IBA was equal or superior to the other auxins is consistent with data from previous loblolly and slash pine rooting experiments (Grigsby 1962, Hare 1974). In addition to the reported observations, we noted that IBA and IAA induced a faster rooting response compared to IPA and NAA, as well as healthier appearing roots in both loblolly and slash pine.

Several treatment combinations in experiment 1date 1 produced greater than 25% regeneration rates. Most of the failure to root (and therefore regenerate) in all treatment combinations appeared to

Table 3—*Summary of rooting (R), shooting (S), and regenerating (P) data for experiment 2*

Species	Age of stock plants (yrs)	No. of stock plants sampled	No. fascicles cultured	R%	S%	P%
Slash pine	1	13	195	72	16	12
	2	6	90	26	0	0
	3	7	105	7	0	0
	5	7	105	7	0	0
	7	7	105	3	0	0
Loblolly pine	1	14	105	15	6	1
	2	7	105	1	0	0
	3	7	105	1	0	0
	5	7	105	0	0	0
	7	7	105	1	0	0
Longleaf pine	1	3	45	31	0	0
	2	7	105	30	28	9
	3	4	75	49	1	0
	5	7	105	0	0	0
	7	7	105	0	0	0

R%, S%, and P% same as in table 1.

Table 4—*Analysis of variance results for rooting data in experiment 2.*

Source	df	MS
Species	2	.387*
Age	4	.418*
Species × age	8	.173*
Error	82	.014

*Significant at the .01 level of probability.
Notes: Species were loblolly, slash, and longleaf pine. Ages were 1, 2, 3, 5, and 7 years from seed. MS = mean square, df = degrees of freedom.

be associated with fungal contamination of the fascicles. The contamination increased with time, so that treatments producing slower rooting responses were more affected. However, from our observations, we concluded that the contamination did not bias treatment comparisons, and that a reduction in contamination would improve the rooting responses of all treatments. It also appears that extreme care in raising the stock plants is necessary for successful fascicle propagation. In agreement with Isikawa and Kusaka (1959) and Zeng (unpublished data), we observed that mature, slightly swollen needle fascicles from vigorous stock plants responded best in culture. Physical manipulations of the stock plants, such as hedging, strangulating (Koh, Menzies, and Hong 1990), or girdling, appear to be the best methods of promoting viable fascicles.

We are uncertain as to any apparent influence of collection date upon root and shoot initiation differences in experiment 1. One hypothesis is that physiological changes detrimental to root and shoot initiation occurred in the stock plants between the collection dates (29 November to 12 February = 78 days). This seems reasonable in light of many time-of-year rooting experiments in pine species, which show seasonal variation in root initiation (Reines and Bamping 1964, Boeijink and Broekhuizen 1974, Struve and Blazich 1984). Thus, our November collection may have occurred during a physiologically optimal rooting and shooting opportunity. Future experiments will need to further address this factor to indicate proper timing for needle fascicle collection.

The response of the 1- to 3-year-old longleaf pine to this propagation system is intriguing. Longleaf pine seedlings, unlike loblolly and slash pine, remain in a grass stage of development (that is, stemless) for 2 to several years following germination. The non-declining rooting response of 1-, 2-, and 3-year-old longleaf pine may be associated with the grass stage of development, since these stock plants were in the grass stage, while the older longleaf stocks were not. It will be interesting to learn whether or not the grass stage maintains an aging tree in a juvenile condition. We conclude that a water-based needle fascicle culture technique has potential for the rapid vegetative increase of southern pine seedlings, especially longleaf seedlings, since the grass stage of this species severely limits the production of standard stem cuttings.

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Moisture Determination on Seeds of Honeylocust and Mimosa

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Moisture determinations with two hardseeded legumes-honeylocust, Gleditsia triacanthos *L., and mimosa,* Albizia julibrissin *Durazzini--clearly showed that seed coats must be ruptured in some fashion to allow all moisture to escape during ovendrying. With these species, cutting the seeds in half was equivalent to grinding for this purpose. In a comparison of grinders, a small coffee mill performed just as well as a Wily laboratory mill, but its durability with large hard seeds may be questioned. According to the Karl Fischer technique run on an automatic analyzer, ovendrying methods provided accurate measurements of moisture for honeylocust but underestimated moisture in the smaller mimosa seeds.* Tree Planters' Notes 43(3):72-75: 1992.

There are two primary reasons for measuring the moisture content of seeds. One is the requirement that all seeds bought and sold in international commerce be tested for germination, purity, and moisture content. The second is seed workers' need to know the condition of the seeds that they are extracting, cleaning, and storing. In commercial transactions, moisture determinations must be accurate and precise, and most countries use the procedures of the International Seed Testing Association (ISTA) for official tests. In routine seed handling, accuracy is also desirable but the precision required is much lower.

Seed moisture content is expressed as a percentage of wet weight (International Seed Testing Association 1985). In any test for moisture content in which loss of weight is equated with loss of moisture, anything that prevents complete loss of moisture from the sample during drying (such as an impermeable seed coat) will produce inaccurate results. Incomplete moisture loss will produce a weight loss that underestimates the moisture content of the sample when moisture is expressed as a percentage of sample weight.

In determinations of seed moisture in official tests (ISTA 1985), grinding is required for "large seeds" and all seeds of species listed in the ISTA rules (table 9A, section 9.5.4.). Large seeds are ground to ensure complete moisture removal and shorten the drying period (Grabe 1989). Although no leguminous tree species are listed in the ISTA rules (table 9A), past experience suggests that intact seeds (even small ones) with very hard coats may require grinding for complete moisture removal during ovendrying. Coarse grinding (50% of the material passing through a 4.0-mm mesh sieve) is required for "leguminous and tree seeds" (ISTA 1985), but it has been demonstrated that for oaks, simply cutting the acorns into two to four pieces provides complete drying and accurate determinations by the oven method (Bonner 1974). Many seed laboratories in developing countries of the tropics do not have the type of grinders required by the ISTA rules. The objective of this study was to determine if alternatives to grinding by the official test procedures can provide accurate measurements of moisture in selected leguminous tree seeds.

Materials and Methods

Seed material. Two leguminous species were used in the study: one with a relatively large seed, honeylocust (*Gleditsia triacanthos* L.), with 5,000 seeds/kg) and one with a small seed, mimosa (*Albizia julibrissin* Durazzini), with 24,000 seeds/kg). Four seed lots of each species were tested. All except one lot were collected in the locality of the Forestry Sciences Laboratory, Starkville, Mississippi, in 1987-89. One lot of honeylocust seeds from South Dakota was purchased from a commercial dealer. The seeds were extracted from their pods with a mechanical macerator and stored at 4 °C until the tests were run.

Preliminary tests were carried out on single lots at low moisture contents (near 10%) to establish procedures. The final test used four lots of each species and two moisture levels of each lot. Two levels were used to increase the repeatability of the results. A higher moisture level (approximately

15%) was achieved by placing samples in a darkened, moist chamber at 40 °C for 1 and 2 days for mimosa and honeylocust respectively. Following this treatment the seeds were returned to storage for 6 weeks before tests were performed.

Treatments. The following measurement techniques were compared on both species:

1. Oven method, intact seeds
2. Oven method, seeds ground in a Wiley mill
3. Oven method, seeds ground in an electric coffee grinder
4. Oven method, seeds cut in half
5. Karl Fischer technique with automatic moisture analyzer

A 1-mm mesh screen was used on the Wiley laboratory mill. The coffee grinder was an inexpensive model available in many retail outlets. Tests with the coffee grinder determined that the percentage of ground material that passed through a 3-mm mesh was 99% for mimosa and 83% for honeylocust. Mimosa seeds were cut in half with nail clippers, and honeylocust seeds were cut with small pruning shears.

Determinations of seed moisture according to Karl Fischer's analysis technique (Grabe 1989) served as the reference method. This technique is widely accepted as the most reliable method for determining seed moisture (Grabe 1989). Measurements were carried out on duplicate samples with an EM Science Aquastar V1B Karl Fischer automatic moisture analyzer. Seeds were first ground in the Wiley mill, and 1-g samples were placed in 50 ml of anhydrous methanol for 48 hours. Determinations of moisture were made on 1.0-ml aliquots.

Drying procedure. Ovendrying was carried out in a mechanical convection oven at 103 ± 1 °C for 17 hours (ISTA 1985). Samples were dried in round aluminum cans (47 by 22 mm) and cooled in glass desiccators over indicating silica gel (6 to 16-mesh) for 45 minutes before reweighing. Samples typically weighed 3 to 5 g, although a limited supply of mimosa seeds at the low moisture level required the use of some samples weighing only 1 g. Each measurement technique was replicated five times at both moisture levels in each seed lot. All samples were weighed to three decimal places on an electric pan balance, and moisture contents were expressed as a percentage of wet weight (ISTA 1985). Moisture percentages were transformed to their square roots (Steel and Torrie 1960) before analyses of variance (ANOVA) were run separately for each of the four species-moisture level combinations. Following ANOVA, treatment means were compared by Duncan's new multiple range test.

Results

Honeylocust. With this larger of the two leguminous seeds, rupturing the seed coat was necessary to completely dry seeds at low moisture contents. Measurements with intact seeds yielded significantly lower values than the other techniques (tables 1 and 2), demonstrating that not all moisture was removed during drying.* Cutting and grinding means (both mills) were not significantly different from results from the Karl Fischer technique, but the Wiley mill mean was significantly higher than the cutting mean (12.0 versus 11.4). There were also significant differences among the seed lots, as expected, probably due to differences in initial moisture contents and seed coat hardness.

Table 1—*Treatment means for both species and moisture levels*

Treatment	Seed moisture content (%) Low	High
Honeylocust		
Intact	9.6 a	15.5 a
Cutting	11.4 b	17.8 b
Wiley mill	12.0 c	16.7 ab
Coffee mill	11.6 bc	17.6 b
Karl Fischer	11.6 bc	15.7 a
Mimosa		
Intact	5.3 a	10.0 a
Cutting	9.4 b	13.4 b
Wiley mill	9.6 bc	12.9 b
Coffee mill	9.8 c	13.4 b
Karl Fischer	11.7 d	15.6 c

All samples were dried for 17 hours in aluminum cans. Means not followed by the same letter differ at $P \leq 0.05$.

*Assuming the Karl Fischer technique is the correct determination, measurement techniques that yield significantly lower moisture contents do so as a result of incomplete drying due to moisture retention in the seed. For example, assume the correct wet and overdry weights of a seed lot are 100 g and 90 g (% moisture content of 10%). However, if due to incomplete drying the wet and overdry weights are 100 g and 95 g, respectively, the false moisture content is now 5%.

Table 2—*Analyses of variance for all species–moisture level tests*

Source	df	Sums of squares	Mean square error	F ratio
Honeylocust—low moisture				
Seed lot	3	0.1185	0.0395	3.58*
Treatment	4	1.7216	.4304	39.02*
Interaction	12	0.8945	.0745	6.76*
Error	80	.8825	.0110	—
Honeylocust—high moisture				
Seed lot	3	1.4640	0.4880	8.28*
Treatment	4	1.3839	.3460	5.87*
Interaction	12	2.4102	.2008	3.41*
Error	80	4.7147	.0589	—
Mimosa—low moisture				
Seed lot	3	1.0534	0.3511	86.63*
Treatment	4	13.8957	3.4739	857.06*
Interaction	12	0.3256	0.0271	6.69*
Error	80	.3243	.0041	—
Mimosa—high moisture				
Seed lot	3	2.0581	0.6860	27.90*
Treatment	4	6.4036	1.6009	65.10*
Interaction	12	0.3925	0.0327	1.33
Error	80	1.9672	.0246	—

*Significant at $P \leq 0.05$.

At the higher moisture level, there was not much difference among technique means (tables 1 and 2). There was no significant difference in moisture between intact seeds and seeds tested by the Karl Fischer technique (15.5 versus 15.7%). The other three treatments (cutting and the grinding mills) had higher means (16.7 to 17.8%), but no significant differences among them. Imbibition had apparently softened the seed coats so much that even intact seeds lost their moisture readily in the oven. There was also wide variation among the measurements at the high moisture level. Lot means were significantly different, as the treatment did not produce equal moisture levels in all lots.

Mimosa. In the smaller seeds of mimosa, the results were similar to those of honeylocust, except that the seed coat seemed to have a much greater effect on moisture loss. At the low moisture level, much more moisture was lost during drying from ground or cut seeds as compared to intact seeds (tables 1 and 2). There was little difference among means for cutting and grinding (both mills), but values from the Karl Fischer technique were significantly higher than means for all other techniques. As with honeylocust, there were significant differences among seed lots.

At the high moisture level of mimosa seeds, intact seeds still gave significantly lower moisture values than any other technique, but the differences were not as much as in the low moisture level (tables 1 and 2). There were no differences among results from cutting and grinding, but moisture determination by the Karl Fischer technique showed that none of the oven methods removed all of the moisture from these seeds. Differences among seed lots were significant at this level also.

Discussion

The results of this study clearly show that the hard seed coats of honeylocust and mimosa must be ruptured in some fashion to allow all moisture to escape during drying, although rupture appears to be more important for seeds with low moisture contents. It is also apparent that in most cases cutting the seeds in half can give results equal to those obtained with ground seeds. This finding could be very helpful to workers in remote field stations or in developing countries where equipment may be limited. The goal in official testing for this type of tree seed is to be accurate to within 0.1 % of true moisture content and to have no greater difference between replicates than 0.3% (ISTA 1985). Cutting should not be adopted for official testing without additional research, but it certainly would be suitable for routine moisture tests for internal use. Most workers agree that accuracy to within 1.0% of true moisture is adequate in those cases.

Although a comparison of grinding mills was not a major objective of this study, the results did show that there was no difference between Wiley and coffee mills for both species. It is possible that for bigger and harder seeds, the coffee mill would not perform as well. In fact, one blade on the coffee mill was broken while grinding honeylocust seeds. Some leguminous tree seeds are extremely hard, and even a Wiley mill would have trouble grinding them when they are dry. The coffee mill should be used on small seeds only. For this reason cutting is even more attractive as an alternative to grinding, although very large seeds might have to be broken with hammers instead of being cut with hand shears. Cutting is not as fast as grinding, but neither method is time-consuming.

For honeylocust seeds, there was good agreement between results of the Karl Fischer technique and the ovendrying methods with ground samples, especially at the low moisture level. The same procedures used with mimosa showed that none of the oven methods were apparently driving all of the moisture out; there was approximately 2% difference between the best oven methods and the Karl Fischer technique. One explanation could be that the silica gel was giving up moisture to the seed material as suggested by Hunt and Neustadt (1966). This is not likely, however, because it did not occur with honeylocust. Another possible reason is stronger chemical bonding of moisture in mimosa.

A weakness of this study was the excessive variation in sample moisture content, which resulted in part from differential uptake of moisture by individual seeds. The presence of insect larvae was another source of error that was difficult to avoid, especially when grinding seeds. High-moisture seeds do not grind as well as seeds with lower moisture levels either, and the ground material tends to form small clumps.

Four seed lots per species were used in this study to ensure a variety of seed conditions and characteristics. Significant differences in moisture content among lots demonstrated that this objective was met, although these differences do not detract from the main goal of the study. Significant interactions between seed lot and treatment in three of the four tests, however, is a different matter (table 2). This could mean that some techniques are not as effective with seed lots with certain characteristics (seed coat thickness, insect infestation, etc.). Additional tests with a greater number of seed lots would be useful in this regard.

Although more research with these and other leguminous tree seeds is recommended, several conclusions can be drawn from the present work:

1. Rupture of seed coats is required for total escape of moisture during drying, and cutting seeds in half seems equal to grinding them for this purpose.
2. The coffee mill proved equal to the Wiley mill in grinding these species, but the coffee mill may not be durable enough for repeated grinding of large seeds such as *G. triacanthos.*
3. Compared to moisture determinations made using the Karl Fischer technique, the oven methods used in this study gave accurate measurements of moisture in honeylocust but did not completely remove the moisture in mimosa seeds. This species deserves more study.

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Performance of Himalayan Blue Pine in the Northeastern United States

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Based on its performance in an area with a large weevil population, Himalayan blue pine (Pinus wallichiana *A.B. Jacks) is not weevil resistant and any growth potential in this area is disguised by repeated weevil attacks. Blue pine may have desirable traits that should be studied outside the areas of greatest weevil concentration.* Tree Planters' Notes 43(3):76-80: 1992.

Because plantations of eastern white pine (*Pinus strobus* L.), the only native soft pine in the northeastern United States, are frequently damaged by numerous insects, diseases, and atmospheric pollutants (Garrett 1985), attempts have been made to develop resistance in this species since the 1930's. Another approach would be to find a different species with similar characteristics that could be used as a substitute for, or in hybrid combination with, eastern white pine.

Exotic 5-needled pines have been planted in this region and some have exhibited varying levels of resistance to blister rust (*Cronartium ribicola* J.C. Fisch. ex. Rabenh) and/or white pine weevil (*Pissodes strobi* Peck). However, only Himalayan blue pine has been planted in numbers large enough to provide meaningful information.

Himalayan blue pine (also known as *P. excelsa* Wall., *P. griffithii* McClelland, and *P. chylla* Lodd.), is a major component of middle- and high- elevation Himalayan forests from eastern Afghanistan to Yunnan Province in China. This 5-needle pine in the genus *Pinus*, subgenus *Strobus*, is closely related to the North American *P. strobus* in the East and *P. monticola* in the West, and closely resembles both of these species in many morphological characteristics. On good sites in its native range, this species is one of the fastest growing conifer species in the world and reaches heights of 50 m (165 feet) (Ahsan 1972).

With the extensive range of blue pine and its discontinuous distribution at elevations of 1,500 to 3,400 m (5,000 to 11,000 feet), there is a strong possibility of geographic variation. Dogra (1972) reported several altitudinal races from different regions in the Himalayas, and Siddiqui (1972) identified mesic and xeric types in northern Pakistan.

Wright and Gabriel (1959) planted several specimens of blue pine near Philadelphia (lat. 40° N, long. 75° W) and reported excellent growth and form. Their observations that this species is rarely attacked by the white pine weevil supported earlier comments by McAloney (1943). Lemmien and Wright (1963) reported that they found 3 times as much weeviling in a 32-year-old planting of blue pine as in eastern white pine of the same age in southern Michigan (lat. 42° 20' N, long. 85° 20' W). Reports by Clinton and McCormick (1919), Spaulding (1925), Childs and Bedwell (1948), and several others in recent years indicate that blue pine is resistant to blister rust (Garrett 1985).

Kriebel and Dogra (1986) reported on a planting of single-tree seedlots from Afghanistan, Pakistan, India, and Nepal that were established to study the cold-hardiness of blue pine in Ohio (lat. 40° 15' N, long. 82° W). Most of the sources from the monsoon side of the western Himalayas were faster growing but less cold-tolerant than those from the drier eastern slopes of the Himalayas. They concluded that it should be possible to extend successful plantings of this species northward in the eastern United States by careful selection of suitable provenances. They also concluded that cold hardiness is the limiting factor, but that there is wide genetic variability in this trait that can be exploited.

Many of the same seedlots tested in Ohio were planted in 1988 in Tennessee (Schlarbaum and Cox 1991), where less than 50% survived at each of three locations. Low survival was attributed to drought conditions. Tennessee may be a good location for studying growth rates but probably is not suitable for studying cold-hardiness or weevil resistance.

Several of the studies in Ohio and elsewhere were looking not only at the performance of this species for timber qualities, but also as another species that could be used as a Christmas tree and in the landscape trade. The tree received its name because the foliage appears bluer than other pines. The needles also tend to be slightly longer than eastern white pine and droop at the ends, giving the tree an attractive appearance.

Because blue pine crosses so readily with eastern white pine, a number of plantings of hybrids between these species has been established in the United States and Canada. Again, results have been contradictory. Wright (1959), Kriebel (1963, 1983), and Radu (1976) reported excellent growth of *P. strobus* X *P. wallichiana* and the reciprocal cross in the nursery. Measurements of Wright's trees 20 years after outplanting indicate that the *P. strobus x P. wallachiana* hybrids were about the same size as *P. strobus* and that the *P. wallichiana* X *P. strobus* were shorter (Garrett 1979). Heimburger (1964) reported a higher than expected proportion of rust-resistant seedlings of the *P. wallichiana* X *P. strobus* hybrid. Zsuffa (1979) reported that *P. strobus* X *P. wallichiana* outgrew *P. strobus* by 60% at age 6 in southeastern Ontario. Garrett (1970) found that grafted *P. strobus* X *P. wallachiana* was as severely and uniformly weeviled as "susceptible" *P. strobus* in the same area of southern Maine.

Materials and Methods

Because many of the earlier papers were based on observations of small or unreplicated plantings in areas where weeviling is not serious and the results were contradictory, we established progeny/ provenance tests in the Northeast to evaluate growth and weevil resistance. Fifty-six half-sib seedlots from six provenances of blue pine were obtained from the Pakistan Forest Institute in Peshawar. A completely randomized, single-tree plot design with 10 replicates per seedlot was planted during the spring of 1976 on the Massabesic Experimental Forest in York County, Maine (lat. 43° 30' N, long. 70° 45' W). Four row plots, each containing 10 eastern white pine seedlings from a local source, were randomly located throughout the planting for comparison purposes (figure 1).

Trees were planted on an area that had supported a vigorously growing stand of white pine. The area was logged, stumps removed, and the ground rotary-tilled before planting. Rows were 2.5 m (8 feet) apart and trees within rows were 1.8 m (6 feet) apart. The space between trees was

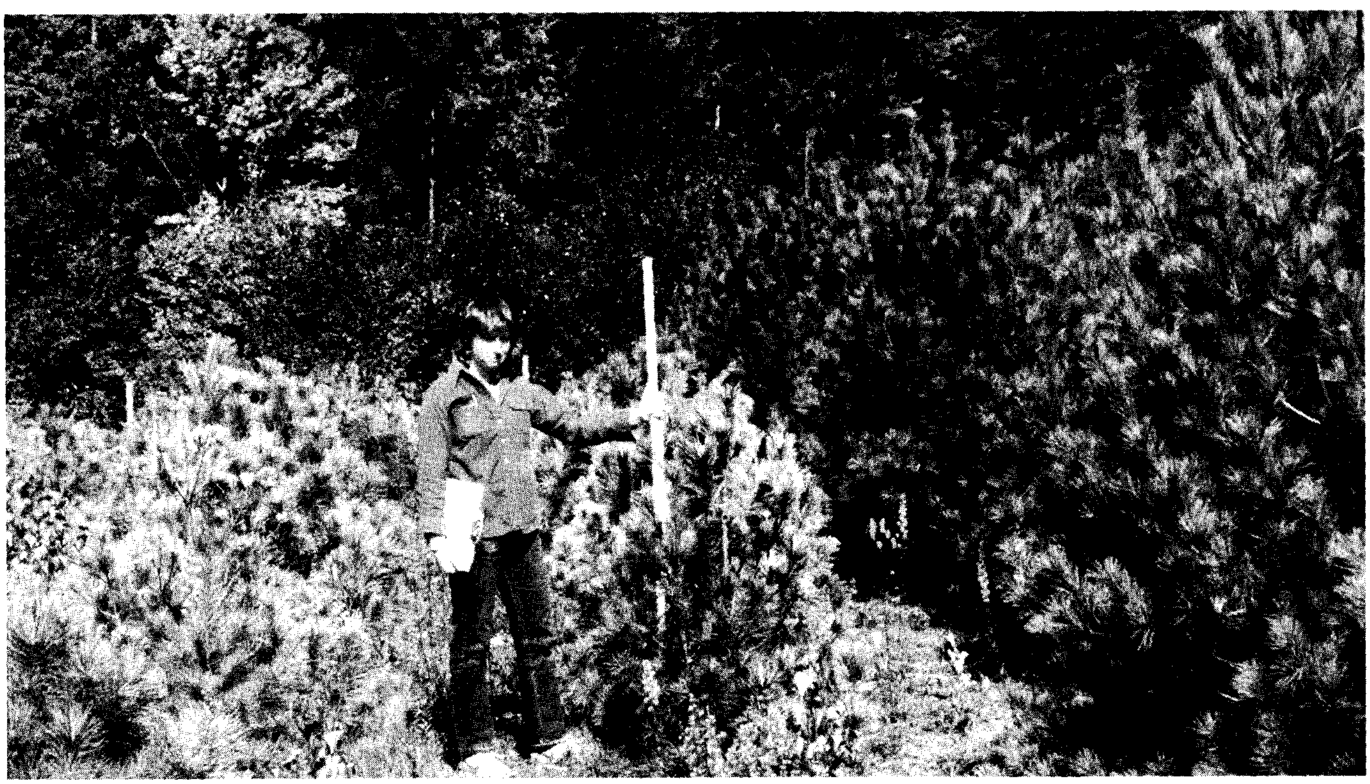

Figure 1—*Blue pine provenance/progeny trial in southern Maine. These seedlings planted in May 1976 were photographed in September 1984. Note the shorter, badly weeviled blue pines on the left and the taller controls of eastern white pine on the right.*

mowed periodically to eliminate weeds and volunteer white pine reproduction. Damage by the white pine weevil was evident on trees of all ages in surrounding stands and throughout the area, so uniform exposure was anticipated.

Seedlings were grown in the greenhouse for 7 months and then planted in the field so the total ages from seed are effectively 5 and 10 years. Survival and heights were recorded at 4 and 9 years after planting and weeviling was recorded at 9 years. Only successful weeviling (dead main-stem leader and larval cavities) as opposed to unsuccessful weeviling (feeding punctures, resin flow, possible reduced growth) during the previous spring was counted. It was apparent that successful weeviling had occurred in previous years, but it would have been difficult to differentiate weeviling from main stem offsets due to other causes.

ANOVA was used only on the heights at age 9. Weeviling data only reflected the current years' injury.

Results

Survival and cold injury. Survival of all planted blue pine was 99% at the end of the fourth growing season and remained an acceptable 85% after 9 years (table 1). Survival of blue pine provenances in 1984 ranged from 92 (Bagh-e-lela) to 79% (Kern and Kalabagh). There was no visible injury to either buds or shoots that could be attributed to cold temperatures in spring or fall. Older needles of blue pine tend to turn yellow earlier than eastern white pine in the fall before shedding, and most needles are a lighter color throughout the winter season.

Because past weeviling attacks and height are related, these traits are discussed together.

Height growth of the blue pine through age 4 was similar to that of the white pine but by 1984 white pine was more than twice as tall as blue pine (table 1). There were statistically significant differences for height growth, probably because of the large differences in means between the provenances of blue pine compared to those of the white pine.

Weeviling is a serious problem in this location and may explain some of the difference in height growth between the two species. We recorded only dead current-year leaders, and weevil damage before age 9 undoubtedly was responsible for some reduction in growth. Weeviling between provenances of blue pine ranged from 47 to 86% and weeviling of white pine was 51% at the same age (table 1).

Table 1—*Height, survival, and weeviling of blue and white pines in Maine*

	Height (ft)		Survival (%)		Weeviling (%)
Provenance	Fall 1979 4 yrs	Fall 1984 9 yrs	Fall 1979 4 yrs	Fall 1984 9 yrs	Fall 1984 9 yrs
Bagh-e-lela	1.56	3.69	99	92	47
Bamburet	1.39	3.30	100	88	49
Kalabagh	1.83	3.19	98	79	86
Kalkot	1.65	3.62	100	84	67
Kern	1.51	3.33	98	79	67
Utror	1.58	3.35	97	81	67
White pine	1.89	7.77	100	100	51

Blue pine has large-diameter terminal leaders, which may account for the species being so susceptible to weevil attacks at a younger age, compared to eastern white pine. It is well known that the larger diameter leaders of open-grown eastern white pine are more susceptible. Because of the short total height of most individuals in this planting, it was difficult to determine exactly when the trees were first attacked or how often this damage occurred. On the basis of feeding scars and offsets on the main stems, it appears that the blue pines were weeviled frequently prior to 1984, where as white pine was just beginning to be attacked at that time. This would be a contributing factor to the height differences between species observed in 1984.

Although this finding wasn't addressed statistically it is interesting to note that the tallest provenance (Bagh-e-lela) also had the highest survival and the lowest weevil attack in 1984. However, if one were looking for favorable combinations of traits, it would be advisable to consider seed lots within provenances. Seedlings of lot 144 (Bagh-e-lela) had slightly below-average height but 100% survival and only 13% weeviling. Lot 173 (Bamburet) had above-average height, 100% survival and only 22% weeviling. Individuals within progenies also expressed variable growth and weeviling that might be useful. Sixteen blue pine trees in this planting were at least 1.74 m (5.7 feet) tall and 3 were 2.14 m (7.0 feet) or more. Of these, 4 were not weeviled in 1984, though they may have been attacked in previous years. Six of the white pines were more than 3.1 m (10.0 feet) tall and 2 of these were unweeviled.

Discussion

The distribution pattern of blue pine suggests that natural variation at the seed source level could have developed for a number of important traits such as growth rate, cold tolerance, and needle color and retention. Studies in Pakistan confirm that provenances do perform differently on different sites (Siddiqui 1988). Seed lots or individual tree selections within provenances throughout the native range of blue pine would be expected to yield trees with acceptable growth rates on some sites in the eastern United States and Canada. Blue pine's compact form and desirable foliage color during the juvenile growth period, desirable traits for landscape purposes or for Christmas tree production, was another reason for looking at this species in the Northeast.

On the basis of our results with this limited number of provenances and progenies, we conclude that:

1. Survival of blue pine when planted this far north (lat. 43° 30' N) is at an acceptable level.
2. Himalayan blue pine is slower growing than native white pine in southern Maine for several possible reasons.
3. Blue pine is at least as susceptible to white pine weevil damage as eastern white pine in the Northeast where heavy weeviling is a frequent occurrence.
4. Early yellowing and loss of older needles in the fall season would be a drawback for Christmas tree growers at this latitude.

Although our planting contained more provenances and progenies than any other trial outside of Pakistan or India at the time, it was still limited to a relatively few sources from about one-quarter of the natural range of this species. Based on our observations 9 years after planting in the field, Himalayan blue pine would not seem to be a good candidate to replace eastern white pine in the northeastern United States or southeastern Canada.

If additional sources of seed could be obtained from other parts of the range (India, Nepal, Bhutan, and China), additional planting should be established in this same area and in areas more nearly approximating the latitude of the collections (lat. 34° to 37° N), probably between 39° and 41° N. Plantings in those latitudes should retain good needle color later in the season, a trait that is essential in Christmas trees. Such plantings also would be outside the region of heaviest weevil populations, though spraying to control weevil damage would be economically justified for this product.

Additional work is needed with hybrids containing blue pine and other potentially valuable 5-needled pines. The germplasm of blue pine used in previous crossing experiments with other white pine species has not been from "select" parent trees, and even the provenance often was un known. Most work was done in arboreta where individuals of flowering age were available and used regardless of their phenotype or genotype. Therefore, performance of hybrids has been based on the qualities of a few biotypes at most and should not be used as an indication of the genetic potential of this species. The entire white pine species/ hybrid complex is essentially unexplored and could contain solutions to many of the serious problems related to pests and atmospheric pollution in the Northeast.

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Advantages of an Effective Weed Control Program for Populus Hybrids

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Two weed control programs were used to establish two intensive-culture short-rotation plantations containing Populus maximowiczii x trichocarpa *hybrid (NE-388) in central Pennsylvania. As compared to mechanical weed control only, a combination mechanical and chemical weed control program reduced the establishment phase for this clone to less than 1 year. Net results of the mechanical-chemical weed control program, as compared to mechanical only, were greater average tree size variables and total tree ovendry weight at the end of a 4-year rotation. When considered as a marginal investment proposition, the discounted value of the added yield was greater than the added cost of the chemical weed control measures.* Tree Planters' Notes 43(3):81-86:1992.

Populus hybrids are very sensitive to weed competition during establishment. Earlier planting successes in herbaceous plant-dominated ecosystems were best achieved by mechanical or physical weed control (Bowersox and Ward 1969, Ford and Williamson 1952). Cunningham and Sower (1962) evaluated varying rates of simazine and reported that cultivation alone produced higher 2-year-old survival and more than double the 2-year-old height than the best herbicide treatment. In the late 1970's, attempts to culture *Populus* hybrids on large areas in short-rotation biomass systems were limited by the availability of biologically safe and financially attractive weed control measures. In the same time period, the menu of available herbicides was expanding rapidly. *Populus* hybrid plantings vary considerably in sensitivity to herbicide damage. Susceptibility to herbicide damage has been associated with application date (Danfield et al. 1983), tillage (Aird 1962, Akinyemiju and Dickmann 1982a), chemical sensitivity (Akinyemiju and Dickmann 1982b, Dickmann et al. 1977, Netzer and Noste 1978, White et al. 1982a, White et al. 1982b) and parentage (Akinyemiju and Dickmann 1982a, Von Althen 1979).

In 1980 and 1981, cuttings for a *Populus* hybrid were planted to conduct net financial and energy analyses for biomass production under four management strategies (Blankenhorn et al. 1985). Not willing to risk the project on untested herbicides, the researchers established the 1980 plantings with mechanical site preparation only. The 1981 plantings were established by a combination mechanical-chemical site preparation and weed control program (Grado et al. 1988). Since 1980, site preparation and weed control programs have been developed for establishing plantations in the Lake States (Hansen et al. 1983) and Ontario (Barkley 1983). Both these programs recommend pretreatments with non-selective herbicides, mechanical site preparation, and pre-emergence herbicides. In general, our 1981 weed control program was similar to the Lake States and Ontario procedures, and this paper describes the potential advantages of an effective weed control program for intensive culture *Populus* plantations.

Methods

Plantations. Two plantations of *P. maximowiczii x trichocarpa* (clone NE-388) were established on abandoned fields in central Pennsylvania. They were about 30 km southwest of State College and within 1 km of each other. The two plantations were designed to evaluate growth and yield from existing fertility and rainfall (control), fertilization, irrigation, and fertilization/ irrigation and to assess the economics of these cultural strategies in dense plantations. This report focuses on the control trees only.

Each plantation (0.6 ha) consisted of 6 blocks of all treatments, 3 planted in 1980 and 3 in 1981. Planting year was randomly assigned to each block, and control treatment was randomly assigned to 1 of the 4 treatment plots per block. The Basher plantation was on a nearly level flood plain derived from red shale and sandstone and the soil was a Basher site loam (Fluvaquentic Dystrochrept; coarse-loamy, mixed, mesic). The Morrison plantation was on a gently sloping upland area where sandstone and dolomite had weathered to a Morrison sandy loam (Ultic Hapludalf; fine-loamy, mixed, mesic).

Dormant, unrooted cuttings were planted in early May in rows 0.8 m apart and 0.6 m between trees in a row for 0.48 m^2 of growing space per tree. All cuttings came from the same stool bed and were collected in March of the specific planting year. All cuttings were 25 cm long and 0.6 to 1.9 cm in mid-point diameter and stored in wet sawdust at 3 °C. Planting methods were the same for each year, except that the 1980 planting required 2 weeks and the 1981 planting required 1 week. Each plot had 272 study trees that were bordered with 2.4 m of similarly spaced trees. There were 3 border rows on the sides and 4 border trees at the end of each row. A total of 550 trees was planted on each 0.026-ha plot.

Height in the first and second growing seasons was measured weekly to biweekly on independent, randomly selected (without replacement) 10 tree subsets per block. Studies designed to evaluate height growth patterns repetitively measured the same trees. In this study, we wanted to test the differences in average height at various measurement dates. Our procedures were used to eliminate previous measurement bias, but this also created the potential that a subsequent average height could be lower than an earlier average height. Height and stem diameter at 15 cm above ground were measured annually on all surviving trees. Total tree yield from all living trees per block (wood, bark, and branchwood) at age 4 was determined from actual harvest (field weight) and ovendry equations (Blankenhorn et al. 1985). Statistical analyses of the annual tree size variables were conducted on a random (with replacement) 100-living-tree subset of the 272 study trees per block (600 trees per planting year), and on the collective yield from all living trees per block (6 blocks per planting year). Analysis of variance was used for all statistical tests at the 0.05 level.

Weed control. The herbaceous communities in the abandoned fields were undisturbed until scheduled for planting. Plowing and disking prior to planting were the only weed control measures available to establish the 1980 plantations. Preplanting chemical weed control was not possible in these plantings because of limited knowledge on safe herbicides for *Populus* hybrids. In July, invading weeds were reducing height growth (figure 1). To remedy this situation, mowing, hand weeding, and shielded applications of glyphosate were instituted in August. These practices would not have been conducted in a production scale plantation. They were conducted to ensure acceptable survival rates to complete the overall research objective. Survival values at the end of the 1980 growing season average 86%.

In consultation with weed control experts, the researchers organized a weed control program for the 1981 plantings that was started in 1980. In August 1980, glyphosate at 2.24 kg/ha and dicamba 3.36 kg/ha, active ingredients (a.i.) were used at the Basher site and glyphosate at 2.24 kg/ ha a.i. at the Morrison site. A root-absorbed herbicide (dicamba) was used at the Basher site to control a carpet of broadleaf weed seedlings under the main abandon-field herbaceous community. These 1- to 2-cm-tall broadleaf weed seedlings were shielded from the foliar-absorbed glyphosate by the 1-m-tall main herbaceous canopy, and they were considered too young to be controlled by the glyphosate. These conditions were not present at the Morrison site. Most of the recommended pre-emergent herbicides were developed for agronomic crops and their toxicities to *Populus* trees being established from cuttings were unknown. Greenhouse trials were used to select the herbicides most likely to safely control the expected weeds (Blankenhorn et al. 1985). The following herbicides were applied to the plowed and disked soils in spring 1981:

Basher site--post-planting broadcast of a pre-emergent herbicide to control nutsedge (*Cyperus esculentus* L.) (metolachlor at 3.36 kg/ha a.i.) plus a pre-emergent to control grasses and broadleaves (oxyfluorfen at 1.12 kg/ha a.i.).

Morrison site--post-planting broadcast of a pre-emergent herbicide to control grasses and broadleaves (oxadiazon at 8.97 kg/ha a.i.).

The amount of weeds in the establishment year of the 1980 plantings was not measured. For the 1981 plantings, estimates of the amount and type of weeds were determined from four 1.0-m^2 sample plots per block at each site (total N = 24). Control plots were also established on adjacent unplanted areas that were tilled but not treated with herbicide (three blocks with four 1.0-m^2 sample plots per block at each site and planting year). In late August, weeds were cut at ground line and ovendry weights for broadleaves and grass were measured for each plot.

Financial evaluations. Procedures involved in the financial evaluation of the first rotation for a 5-rotation system have been reported by Strauss et al. (1987). An accounting-type cost analysis was used, including the proration of establishment costs over the five 4-year rotations, assessment of an economic rent for land use, and identification of all other operating and maintenance charges. The financial costs were developed for the base year 1981.

Results and Discussion

Tree response. Overall, there were significant differences in average tree diameter and height between planting years at the end of the fourth growing season (table 1). Differences between sites were not significant, except for a small (0.02 cm) but significant difference in stem diameter for the 1980 planting. Therefore, data were pooled over sites to examine differences between planting years. Averaged over sites, the 1980 plantings were 5.5 m in height and 3.4 cm in diameter and had 20.2 ± 5.2 ovendry (OD) tonne/ha of total tree yield at the end of 4 growing seasons. The 1981 plantings averaged 6.7 m in height and 4.2 cm in diameter and had 33.1 - 5.2 OD tonne/ha of total tree yield.

Table 1—*Average 4-year-old survival, total height, stem diameter at 15 cm above ground, and total tree ovendry yield for trees planted in 1980 and 1981*

Planting year & site	Survival (%)	Total height (m)	Stem diameter (cm)	Total tree yield (OD tonne/ha)
1980				
Basher	84	5.7 a	3.5 b	21.7 a
Morrison	88	5.3 a	3.3 a	18.7 a
1981				
Basher	91	6.8 c	4.2 c	34.2 b
Morrison	90	6.7 c	4.2 c	31.9 b

Variable values with the same letter were not significantly different at the 0.05 level. By planting year and site, N was 816 for survival, 300 for total height and stem diameter, and 3 for total tree yield.

Even with the high degree of site, stock, and operational standardization, year-to-year comparisons are difficult to evaluate because of variable weather conditions. Weather conditions in the 1980 to 1984 growing seasons were not extreme, but the extent to which weather influenced the differential growth rates of the 1980 and 1981 plantings is unknown. Rainfall values during the growing seasons did not vary greatly until 1983 (table 2). When the trees planted in 1980 were in their fourth growing season, rainfall was low (1983). When the trees planted in 1981 were in their fourth growing season, rainfall was high (1984).

Table 2—*Rainfall at the study sites during the 1980 to 1984 growing seasons*

Month	Rainfall by growing season (cm) 1980	1981	1982	1983	1984
June	7.6	13.3	10.9	7.1	12.7
July	10.2	7.8	10.5	3.1	7.7
August	8.2	4.7	4.4	1.9	15.2
Total	26.0	25.8	25.8	12.1	35.6

From U.S. weather station 30 km northeast of plantations in 1980. Recorded daily from two rain gauges at each plantation in 1981 through 1984 and averaged together.

Height growth rates during the first and second growing seasons were strikingly different for the 2 planting years (figure 1). At the end of the first growing season, all trees planted in 1980 averaged

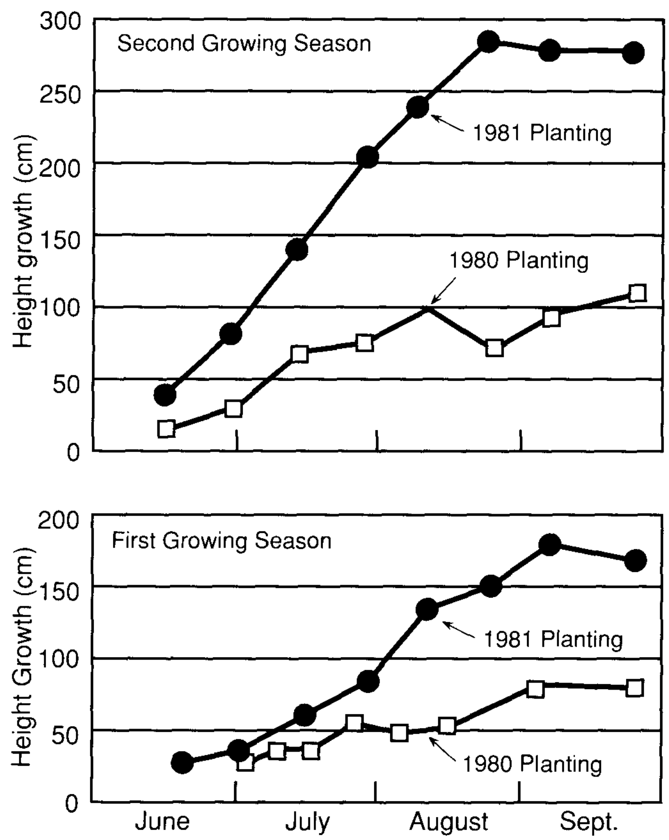

Figure 1—*First- and second-year height values of the 1980 and 1981 tree plantings. Lower sequential values were not significantly different from previous value and were due to sample error. Each value was based on 60 independent trees, averaged over the two plantation sites.*

0.8 m in height whereas all trees planted in 1981 averaged 1.7 m. Compared to the first-year height growth from other central Pennsylvania plantations (of the same hybrid) where weeds were controlled by hand hoeing or black polyethylene mulch (Bowersox and Ward 1969, Bowersox and Ward 1976, Bowersox et al. 1979), the height growth of the 1980 plantings was about 40% lower than what should be expected; that of the 1981 plantings was about 40% higher than what should be expected.

Low rainfall in June 1980 (7.6 cm) may be partly responsible for the reduced height growth in the first growing season for the 1980 planted trees (figure 1), but we believe that weed competition was a more controlling factor. The mechanical site preparation used for the 1980 plantings established a relatively weed free condition until late June. However, by mid-July, the weeds rapidly developed to the height of the trees. Remedial weed control measures were enacted after August 1. Height growth in late July and August 1980 appeared to be very sensitive to weed competition (figure 1). In contrast, the 1981 plantings were relatively weed free through July and once the trees started to grow rapidly in height (early July), their growth was unrestricted. Overall, site preparation and weed control program for the 1981 plantings reduced the weed growth in the Basher and Morrison plantations by 80 and 87%, respectively, when compared to the control plots (table 3). Total amount of weeds in the plantations and the control plots was lower at the Morrison site than at the Basher site. This was largely due to the amount of grasses (mainly nutsedge) at the Basher site.

Table 3—*Ovendry weight of herbaceous vegetation in late August 1981 for herbicide (tilled plus pre-emergent herbicides) and control (tilled only), by site and weed group*

	Basher (g/m^2)		Morrison (g/m^2)	
Weed group	Herbicide	Control	Herbicide	Control
Grasses	25	45	2	12
Broadleaves	30	235	22	178
Total	55	280	24	190

Quality of the establishment-year weed control program appears to have a carryover to the second growing season. Total height growth in the second growing season was markedly greater for the trees planted in 1981 than for those planted in 1980 (figure 1). The 1980 plantings grew an average of about 1.0 cm/day in June, July, and August for a second growing seasonal height growth of 1.0 m.

Trees planted in 1981 grew an average of 2.0 cm/ day during June, July, and August of their second year. After two growing seasons, total height of the 1980 plantings averaged 1.8 m and the 1981 planted trees averaged 4.4 m (figure 2).

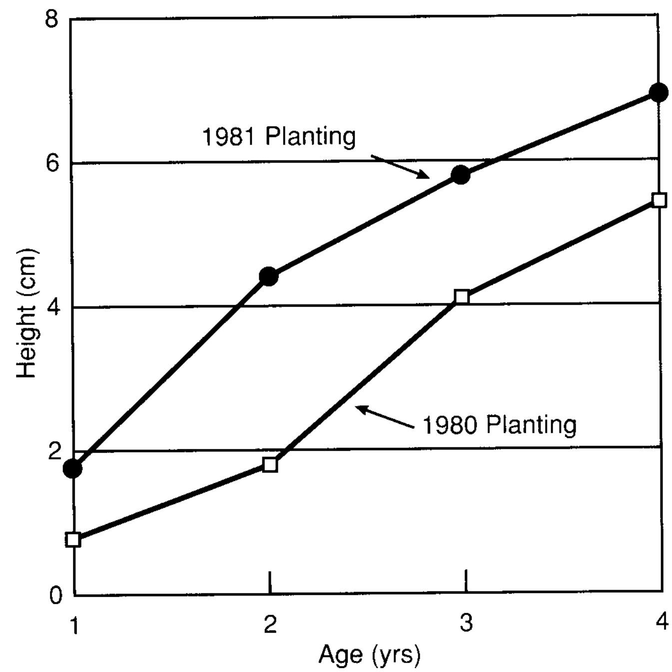

Figure 2—*Average total height for the 1980 and 1981 plantings by age. Values were based on 600 trees, averaged over the two plantation sites.*

Height growth of the 1980 plantings was restricted in the first and second growing seasons and the establishment period was prolonged. Once the trees were well established (1981 plantings by the end of their first growing season and 1980 plantings by the end of their second growing season) total height growth rates were similar (figure 2). Height increment for the second growing season of the 1981 plantings was similar to the third-year increment for the 1980 plantings; third- and fourth- year height increments for the 1981 plantings were similar to the fourth-year increment of the 1980 plantings. In essence, the weed control measures used in the 1981 plantings resulted in an establishment phase of 1 year, whereas the measures used in the 1980 plantings resulted in an establishment phase of 2 years.

Average height, diameter, and total tree ovendry yield for the trees planted in 1981 were greater than for the trees planted in 1980. These differences could have been due to unknown establishment and tending practices, weather conditions, or unique factors for this particular clone at these specific sites. However, we believe the main reason for the differences in average tree size and total tree yield for the 1980 and 1981 plantings was the effectiveness of the establishment-year weed control programs.

Financial response. The potential increase of 64% to the first-rotation yields associated with a weed control program would provide a substantial cost reduction for the short-rotation intensive culture system. Financial evaluations of the commercial-scale establishment and maintenance costs for the plantations, excluding any herbicide treatments, placed the total costs for the first rotation at $942/ha. This included the prorated cost of establishment for the first rotation, the annual maintenance and operating costs, and the economic rent for using the agricultural sites (Strauss et al. 1987). Estimated first-rotation yields of 20 OD tonne/ha placed the stumpage cost for the biomass at $47 per OD tonne. Costs for remedial mowing, hand weeding, and shielded applications of glyphosate used in the 1980 plantings were not included in the analyses, and there is also some possibility that expected yields for the 1980 plantings would have been lower without these treatments.

The chemical weed control program for the 1981 plantings increased the establishment charges by $210/ha; which, when prorated over 5 rotations, raised the end-of-rotation costs to $1,015/ha. However, the more effective weed control program increased yields to 33 OD tonne/ha. The cost of the 1981 weed control program was greater than the 1980 weed control program, but the 1981 program produced substantially more biomass. The net effect of the 1981 weed control program reduced the stumpage costs to $31 per OD tonne, or 34% lower than the less effective (1980) weed control program.

The weed control programs were evaluated as a marginal investment proposition, given two assumptions. These assumptions were (1) the yield increase of 13 OD tonne/ha would only have occurred in the first rotation, and (2) the value of the stumpage was equal to its cost (a financially break-even situation). Using a 5% real rate of return, the discounted value of the 13 OD tonne/ha gain, priced at $31 OD/tonne, was $332/ha. This return exceeded the initial cost of $210/ha for the weed control program and, again, justified its investment.

Conclusions

Populus hybrids are very sensitive to weed competition, particularly in the establishment phase. Establishing plantations from dormant unrooted cuttings requires a unique herbicide program that will both control weeds and cause minimal damage to root and stem tissues. The combined mechanical-chemical program we used for one *Populus* clone in central Pennsylvania was similar to the recommendations for establishing *Populus* plantations in the Lake States and Ontario. The chemicals we used should not be taken as a recommendation. Specific chemicals will vary, depending on soil, climate, weed species, cultural practices, and *Populus* parentages. New products or label changes will require herbicide program adjustments. In this case, for a 4-year biomass rotation, we believe the combined mechanical-chemical weed control measures were cost effective and allowed the trees to more fully exploit the potential of the site.

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Pales Weevil: A Serious Threat to Longleaf Pine Production

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Pales weevil (Hylobius pales *(Herbst)) has become a serious problem to longleaf pine* (Pinus palustris *Mill.) seedlings in North Carolina. The weevil may feed below ground on tap roots or above ground on the seedling bud. Longleaf pine seedlings planted on recently cut pine tracts should be checked for weevil damage at 2 to 4 weeks after planting. If damage from pales weevil is occurring, seedlings should be treated with the appropriate insecticide.* Tree Planters' Notes 43(3):87-88: 1992.

The pales weevil (*Hylobius pales* Herbst) is a serious insect problem in pine reproduction (Drooz *1985).* The insect is attracted to recently cut pine stands. If pine seedlings, either natural or planted, are present in the cutover area, the insect feeds on their stems. Light feeding injuries heal, but heavy feeding results in girdling and seedling mortality. Although pales weevil is known to attack all species of pine within its range, pitch *(Pinus rigida* Mill.), white *(Pinus strobus* L.), shortleaf *(Pinus echinata* Mill.), and loblolly *(Pinus taeda* L.) pines are favored species.

In the past, little damage has been observed on longleaf pine *(Pinus palustris* Mill.). Longleaf pine was considered a low-risk species because only the stout, pubescent bud is above ground line when seedlings are planted. Recently, however, the demand for longleaf "straw" for landscaping purposes has resulted in increased planting of longleaf pines. Longleaf plantations are being established in both fields and on cutover tracts. In the past *2* years, more than *500* acres of longleaf plantations in North Carolina have incurred in excess of *25%* mortality due to weevils. The causative agent is definitely pales weevil, because the insects have been observed feeding.

The injury pattern from feeding by these weevils in longleaf pine differs from that encountered in the other pine species. There are two types of feeding on longleaf pines. The first type is on the taproot, below ground. The weevil cut deep grooves in the taproot (figure 1A) and if feeding heavily, completely debarked the root. The above-ground portion of a longleaf seedling is so short that, when above-ground feeding occurred, the bud was completely consumed, leaving only a tiny stick surrounded by a pile of dead needles (figure 1B).

Several control options are available for minimizing weevil damage. Damage may be avoided by delaying planting for a season on pine tracts that are harvested after June. However, this option results in a year of growth loss and often results in increased site-preparation cost.

Longleaf seedlings planted in areas where pine material has been cut after the previous June should be checked for weevil damage 2 to 4 weeks after planting. If weevil damage is occurring, a registered insecticide may be used for field treatment. The insecticide is applied to individual seedlings in the field with a pressure-type hand sprayer.

Several insecticides are currently registered for use as top dips for protection of pine seedlings from debarking weevils. To use these materials, seedling tops are dipped in the insecticides before planting. Because damage to longleaf seedlings is often in the underground root systems, top dipping will probably be an ineffective control measure. The labels of the currently registered top-dip chemicals specifically prohibit root coverage, so additional studies and label changes will be necessary before these materials may be used to protect root systems.

One systemic insecticide is registered for weevil control on pine seedlings. Although it will probably be effective on longleaf pine, its high mammalian toxicity may preclude general use. Before using insecticides, land managers should check with extension or State forestry personnel to determine currently registered materials.

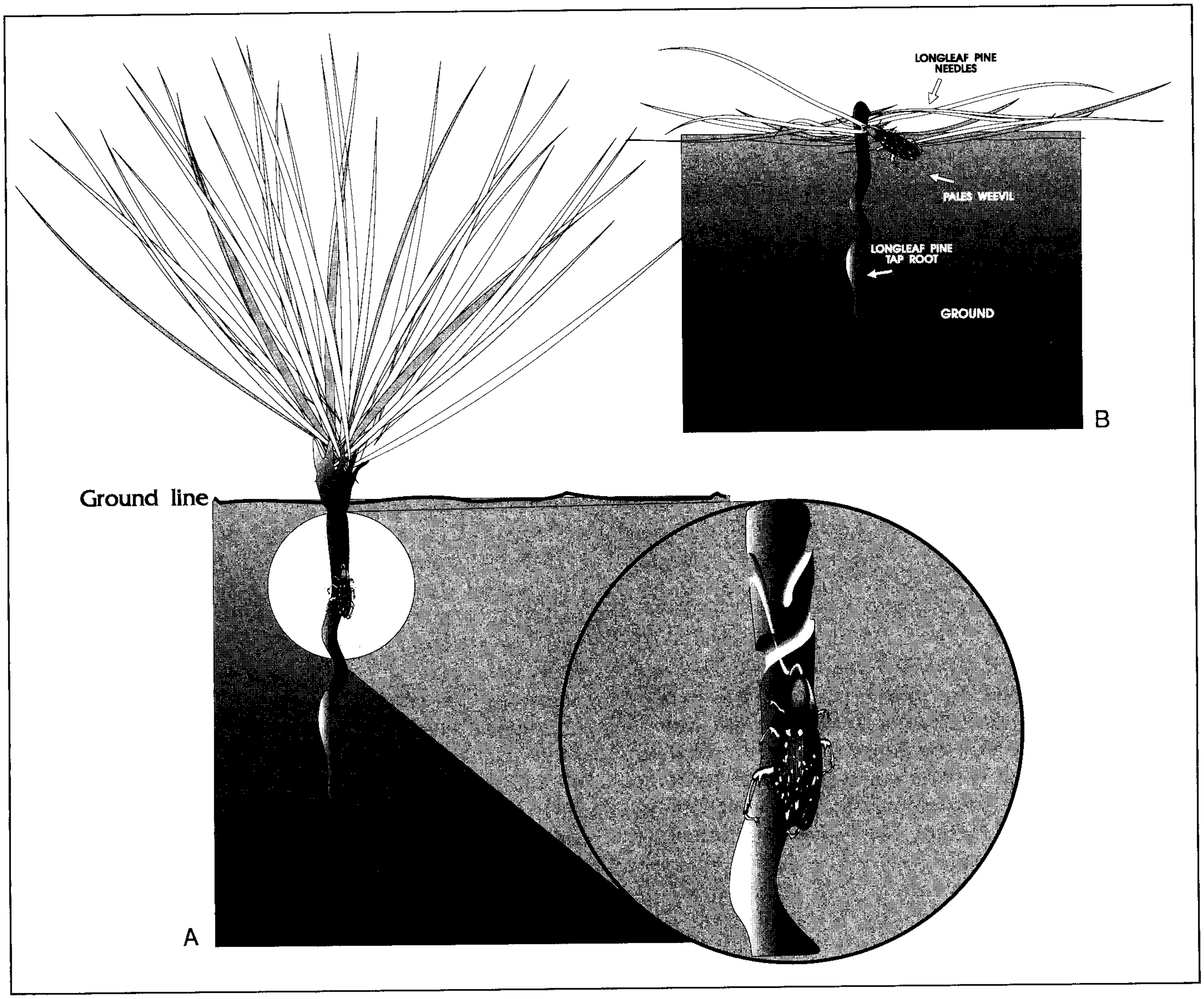

Figure 1A—*Tap root feeding by the pales weevil.* **B**—*Top feeding by a pales weevil.*

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We greatly appreciate the work of Chris Carlson, who prepared the illustrations.

Costs and Cost Component Trends of Hand and Machine Tree Planting in the Southern United States (1952 to 1990)

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Since 1952, 11 periodic surveys on the costs of forest practices have been published. These surveys provide detailed data on hand and machine tree planting costs by geographical region and quality of planting site. Tree planting costs have increased nearly 5% annually since 1952. Hand planting is generally more expensive (20 to 50%) than machine planting. Hand planting costs have increased much more than the general price index, probably because of the amount of direct labor involved. Tree Planters' Notes 43(3):89-92:1992.

Current and future costs of forest management practices in the South are essential information for forest managers and planners responsible for capital allocation decisions. In all businesses it is important to understand the characteristics of the capital costs, and forestry is no exception. Forest products companies maintain detailed records on costs and revenues to assist managers in making decisions on forestry projects.

However, comparable information is usually not available to non-industrial private forest landowners or potential forestry investors. Also, forest managers need reliable cost information when considering alternative forest practices where cost records are not available.

Managers concerned with the costs of tree planting operations may not be aware that southern costs and cost trends for the last 40 years are available for analysis and comparison. *Forest Farmer* has published a series on cost estimates for major forest practices since 1952. Researchers at southern universities collected these cost data by surveying individuals, private firms, and public agencies across the Southern United States. Currently the survey is updated every 2 years and published in the *Forest Farmer Manual Edition.* The cost of tree planting by hand and machine is included in each survey.

A chronological description of the surveys will identify the issues of *Forest Farmer* necessary to utilize this time series. Albert C. Worrell reported the original 1952 cost survey in the May 1953 issue of *Forest Farmer* (Worrell 1953). James G. Yoho and Robert B. Fish updated the original survey in early 1961 (Yoho and Fish 1961). The same 1961 survey was examined in more detail in 1963 (Somberg, Eads, and Yoho 1963). Later surveys were completed in 1967 (Yoho, Dutrow, and Moak 1971), 1974 (Moak and Kucera 1975), 1976 (Moak, Kucera, and Watson 1977), 1979 (Moak, Watson, and Van Deusen 1980), 1982 (Moak, Watson, and Watson 1983), 1984 (Straka and Watson 1985), 1986 (Watson, Straka, and Bullard 1987), 1988 (Straka, Watson, and Dubois 1989), and 1990 (Dubois et al. 1991). Moak (1982) provided an analysis of these cost trends for 1952 to 1979. Straka and Watson (1987) provided additional analysis of the 1984 survey data. Dubois, Straka, and Watson (1991) used the survey data to develop a cost index for southern forest practices.

Tree Planting Cost Trends

Hand and machine tree planting costs for survey years between 1952 and 1990 are reported in figure 1. Planting costs have been reported on a per-seedling basis, because the most significant factor affecting planting costs is the number of seedlings planted per acre. These costs do not include the cost of the seedlings. Of course, these costs can easily be converted to a total cost per acre basis by multiplying the per-seedling cost by the number of seedlings planted per acre. Hand planting costs usually exceeded machine planting costs by 20 to 50%. Hand planting is more common on rough or cutover land, and this may partially explain the cost difference. However, the cost differential between hand and machine plant-

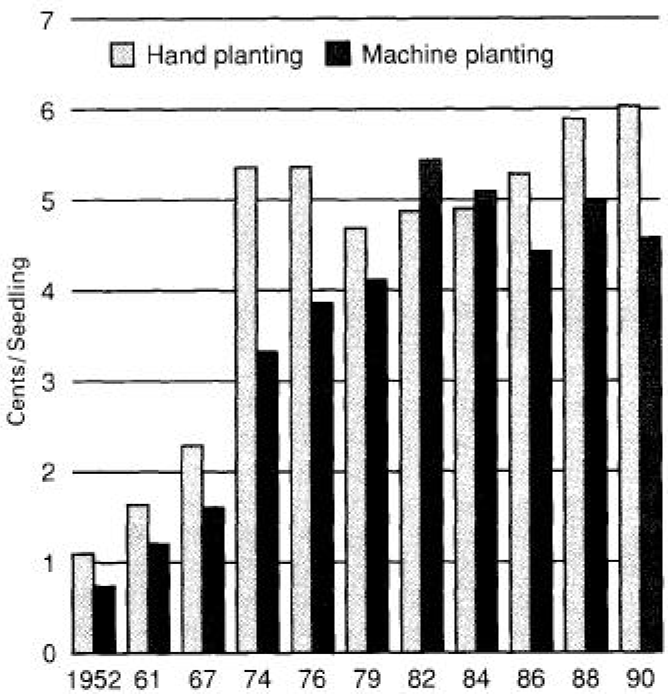

Figure 1—*Cost of tree planting in the Southern United States (1952 to 1990) on a per-seedling basis, excluding the cost of the seedlings.*

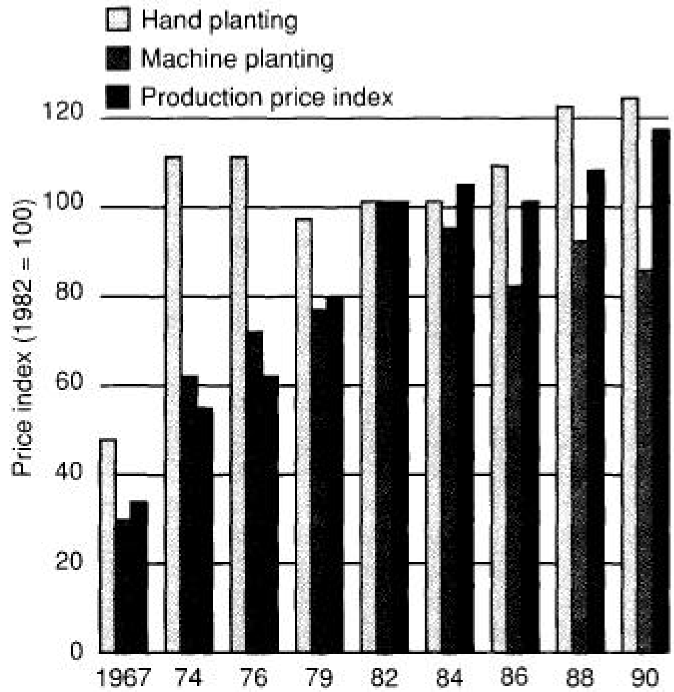

Figure 2—*Changes in the cost of tree planting in the Southern United States related to the producer price index (all commodities).*

ing moderates in later surveys. The quality of planting sites generally increased over the 38-year period and hand and machine planting may be occurring on more similar sites.

Average tree planting cost (by either method) increased approximately 5% annually. Figure 2 illustrates tree planting cost increases relative to the general price index from 1967 to 1990. Relative to the producer price index, machine planting costs have decreased over time. However, labor-intensive hand planting costs have consistently exceeded increases in the general price level.

Direct labor costs dominate the cost of both hand and machine planting (figure 3). Indeed, hand planting is one of the most labor-intensive forest practices. Direct labor has averaged over 70% of total hand planting cost and over 40% of total machine planting cost. Machine planting has over 20% of total cost allocated to both supervision and equipment. Direct labor cost even exceeds equipment cost on machine planting operations.

The surveys contain more detail than the numerical results reported here. For example, the surveys showed no trend for labor costs per seedling to decrease as the number of seedlings planted per acre increased. Also, survey results are reported by region (Southern Coastal Plain, Northern Coastal Plain, and Piedmont) and condition of planting site (average, less difficult than average, and more difficult than average).

Current Cost Trends

Recent surveys provide additional analyses of the survey results. In 1990, respondents classified planting costs according to planting conditions and methods. In addition to noting if planting was carried out by hand or by machine, respondents noted if seedlings were planted on clearcut or old fields and what type of site preparation treatment was carried out before planting.

There was great diversity in the types of site preparation treatments used in 1990. Thus, in subsequent surveys, site preparation was classified as either intensive mechanical preparation or less intensive nonmechanical preparation. The average size of the tract also was reported.

Most of the planting reported (90%) was carried out following clearcutting operations. The average cost of planting old-field sites and clearcuts following both intensive mechanical site preparation and non-intensive mechanical site preparation is presented in table 1.

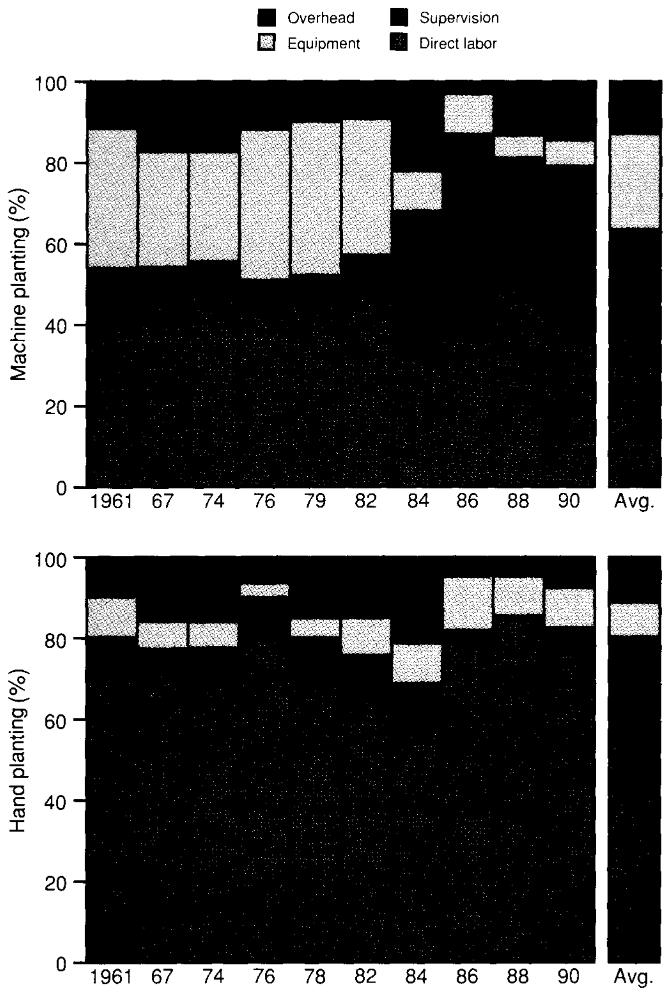

Figure 3—*Cost component trends for hand and machine tree planting in the Southern United States (1961 to 1990).*

Table 1—*Tree planting costs by type of site and planting method (1990)*

Type of site	Average cost ($)	Minimum cost ($)	Maximum cost ($)
Old fields			
Hand	49.06	37.50	80.00
Machine	34.12	25.00	58.00
Cutover sites			
Intensive mechanical site preparation			
Hand	39.00	20.94	195.00
Machine	30.53	17.00	77.00
Non-intensive mechanical site preparation			
Hand	42.80	26.40	102.00
Machine	ID	ID	ID

ID = insufficient data. Values are weighted averages by acreage planted.

Table 1 illustrates highly variable cost data. A statistically significant difference in costs between the Piedmont and uplands regions, as compared to the coastal plain, was observed. Also, tract size was negatively correlated with planting cost. The variability is attributed to the appropriate selection of site preparation and planting strategy by land managers for their situation. Intensive wood utilization during logging and/or a costly site preparation treatment should result in a less expensive planting method. Conversely, a site preparation treatment that does not remove debris from the site usually requires more costly planting methods (Straka and Watson 1987).

The 1988 and 1990 surveys included the costs of planting on acreage in the Conservation Reserve Program (CRP) and cost component data by vendor or company operation. Increased planting costs since 1986 may be due to increased competition for planting vendors due to the CRP planting. Most CRP planting was old-field planting and nearly all the acreage was planted by vendors. Overall, about 683 trees per acre were planted in 1988 to 1990, while CRP plantings averaged 781 trees per acre.

The distribution of planting cost components provides an interesting comparison of planting operations. Table 2 shows this distribution by company and vendor operations. Direct labor and equipment costs obviously vary significantly by type of operation. In 1990, 90% of tree planting was performed by vendors, accounting for 98% of the acreage planted.

Table 2—*Percentage distribution of planting costs by components and type of operation (1990)*

	Vendor operation		Company operation	
Component of cost	Hand planting	Machine planting	Hand planting	Machine planting
Direct labor	10.4	5.6	76.5	41.1
Equipment	3.3	2.4	5.9	38.0
Supervision	9.1	4.9	10.0	6.1
Overhead	8.3	4.1	7.6	14.8
Vendor fee	68.9	83.0	—	—

Dubois et al. (1991) developed a simple cost index for southern forest practices using these data. This "southern forest practice cost index" is similar to the well-known consumer price index. Table 3 presents the index for seeding and tree planting costs. (The third column in table 3 represents a pro-rated average cost index for a variety of forest management activities that typically occur in southern forestry, such as site preparation, controlled burning, planting, etc. Thus, the indexed cost of seedlings went up from 100 to 116 from

Table 3—*Seedling and tree planting (hand and machine, averaged) relative to the southern forest practice cost index, 1982–1984 (base year 1982)*

Year	Seedlings	Tree planting	Southern forest practice cost index
1982	100	100	100
1984	116	97	100
1986	117	98	108
1988	143	113	115

1982 to 1984, while the cost of planting went down and the overall cost of forestry activities, taken as a whole, remained unchanged.)

The seedling cost index rose from a base level of 100 in 1982 to 117 in 1986. A marked increase in the seedling cost index from 117 in 1986 to 143 in 1988 may be attributable to increased seedling demand resulting from the Conservation Reserve Program established in the Conservation Title of the Food Security Act of 1985. In 11 Southern States, over 900,000 acres of cropland were enrolled in the program for tree planting during fiscal years 1986, 1987, and 1988 (Dicks et al. 1988, Osborn et al. 1989). Furthermore, in a 1988 forest practice cost survey, almost 24% of reported planted acreage was enrolled in the CRP (Straka et al. 1989).

The planting cost index fell from 100 in 1982 to 97 in 1984. The drop in the planting cost index may have resulted from an increased availability of planting contractors. According to Guldin (1983), increased interregional mobility of planting contractors increased the number of competitive bids for planting contracts. Increased competition for planting contracts should have resulted in decreased costs for planting. A rise in the planting cost index by 15% from 1986 to 1988 may be attributable to increased demand for planting vendors resulting from the CRP. Furthermore, a possible reduced labor supply resulting from the Migrant Seasonal Worker Protection Act may have also influenced tree planting cost increases from 1986 to 1988.

Summary

A series of 11 surveys of forest practices costs provides detailed data on southern tree planting costs since 1952. The surveys are cited chronologically to provide easy access to researchers or managers interested in the costs of tree planting operations. Data are available on actual costs, relative costs, geographical variations, method of planting, quality of planting site, CRP program planting costs, and type of operation (vendor or company).

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Comparison of a Drill-type Seeder and a Vacuum-Drum Precision Seeder in a Virginia Loblolly Pine Nursery

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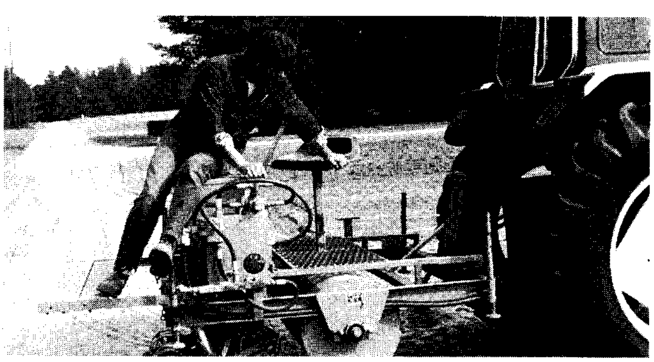
*A 3-year study compared root collar diameter distribution and cull percentages of loblolly pine (*Pinus taeda *L.) sown with either a drill-type seeder (Whitfield) or a vacuum-drum precision seeder (Love). Seedbed densities were similar for each machine. Although the precision seeder distributed seed more evenly, no consistent improvement was seen in uniformity or cull percentage with its use.* Tree Planters' Notes 43(3):93-96: 1992.

The Virginia Department of Forestry has traditionally sown loblolly pine (*Pinus taeda* L.) with drill-type seeders, including Whitfield (figure 1) and Love-Oyjord models. Eight single drill rows are planted down the length of the nursery bed, with average seed spacing determined by setting and tractor speed. Unfortunately, with these machines, seeds tend to be dropped in clumps. Vacuum-drum precision seeders, on the other hand, distribute seeds more evenly by accurately placing them in a precise pattern, with less clumping (Boyer et al. 1985, Pryor and Vedder 1986). The Love precision seeder (figure 2) actually sows 8 double rows down the length of the nursery bed.

The precision seeder has both advantages and disadvantages when compared with drill-type seeders. The precision seeder is easier to calibrate and, of course, produces a much better pattern of seed distribution. On the other hand, it is slower to operate, requires more precise soil moisture conditions, needs frequent cleaning, and requires very clean, sized seed (Boyer et al. 1985, Murphy 1990, Pryor and Vedder 1986). Overall, the precision seeder would need to produce significantly more uniform seedlings to justify its purchase and the greater expense of operation.



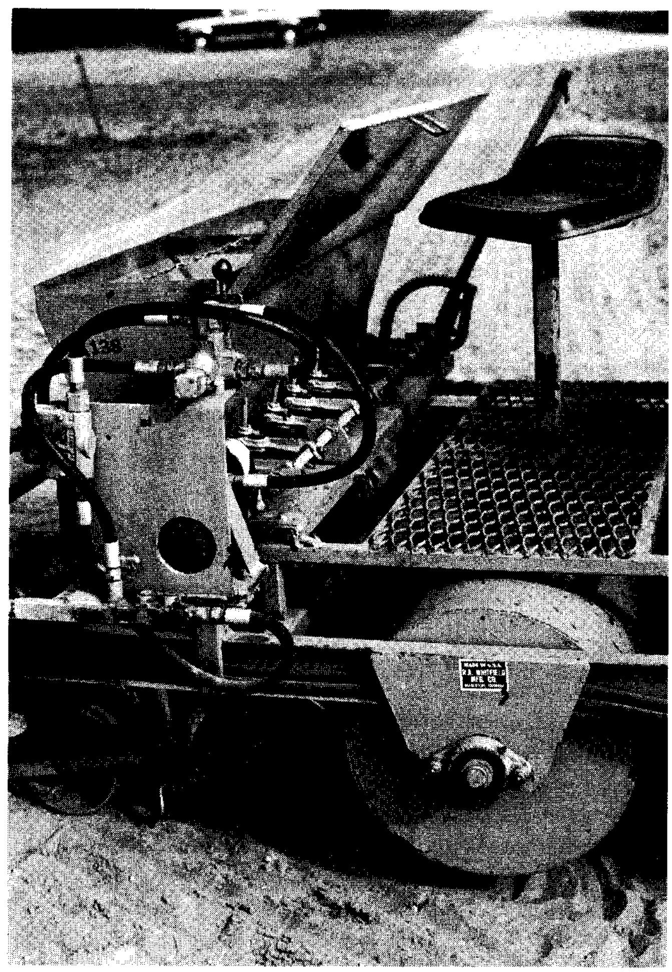


Figure 1—*The Whitfield drill-type sower used by the Virginia Department of Forestry sows single-drill rows with less precise seed spacing.*

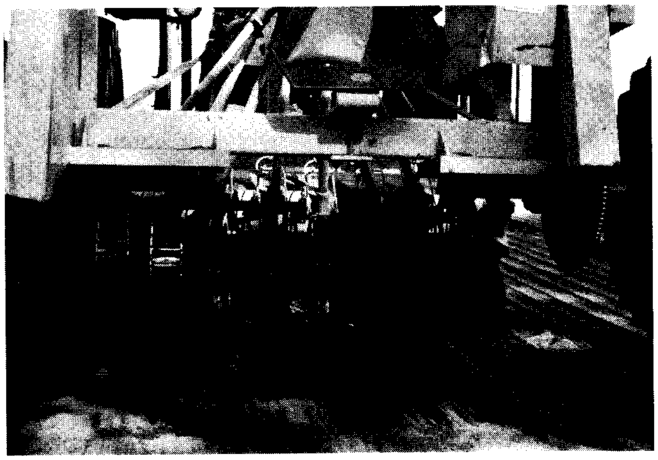


Figure 2—*The Love vacuum-drum precision sower used by the Virginia Department of Forestry sows double-drill rows with more precise seed spacing.*

In 1988, testing was begun to determine the effects of this new spacing pattern on root collar diameter distribution and cull percentage. Our nurseries cull loblolly pine at a diameter of 2.8 mm ($^{7}/_{64}$ inch). Other organizations have studied the effects of the precision seeder's improved spacing on seedling quality. Some have simply assumed that the improved seed spacing would translate into fewer culls (Pryor and Vedder 1986). Others have actually found an improvement with the use of the precision seeder (Vanderveer 1992, Boyer et al. 1985, Murphy 1990), although often at lower seedbed densities than we use operationally.

Our study, carried out during the 1988, 1989, and 1991 seasons, compared the Whitfield drill-type seeder with the Love vacuum-drum precision seeder.

Methods

All 3 years, loblolly pine seeds were sown in adjacent nursery beds with either a drill-type (Whitfield) or a vacuum-drum (Love) precision seeder. The same seedlot and seeding rate were used for both treatments in any given location. Seed purity was high and, in the 1989 and 1991 studies, sized seedlots were used. However, the germination of the seedlots involved was lower than normal, with germinations of 75, 87, 81, and 81% for the 1988, 1989 bulk, 1989 single-family, and 1991 lots, respectively. In each successive year, initial seedbed densities for both treatments decreased, reflecting an intentional trend toward lower stocking. In all years, the growing conditions in the locations chosen were very uniform. In 1988, the study involved just two adjacent beds at our Sussex County nursery. The 1989 and 1991 studies involved six adjacent beds in each of two locations, at our New Kent County nursery. In 1989, the two locations were sown with different seedlots, at each location–one bulk and one single-family lot. In 1991, as in 1988, only one bulk seedlot was used for all beds sown.

In 1988, 10 paired (20 plots) samples were lifted, at 20-foot intervals down the two beds. Each pair was 15.2 cm (6 inches) wide across both seedbeds (seedbeds are 4 feet across), for a total of ten .19-m^2 (2-square-foot) samples for each treatment. In 1989 and 1991, when more space was available, sample locations were randomly chosen. In 1989, 6 pairs (12 plots) at each location, with each seed lot represented in half of the plots of .19-m^2 samples were initially lifted, two in each of the 6 paired beds involved. Seedbed densities in the location sown with the bulk seedlot were much more representative of our typical stocking. Therefore, 4 additional pairs (8 plots) of .19-m^2 samples were lifted in each paired bed, bringing the total to six in each of the six paired beds for a total of 36 plots in that location. In 1991, 12 pairs (24 plots) of .19-m^2 samples were lifted, four in each of the 6 beds involved at each of the two locations, for a total of 48 plots across both locations. In all cases, each pair was lifted using a 15.2-cm-wide (6-inch-wide) gauge, going straight across two adjacent seedbeds, one sown with each type of seeder.

Samples were graded into eight root collar diameter classes with an increment of .79 mm, from a 1.59-mm ($^{2}/_{32}$-inch) class to a 7.14-mm ($^{9}/_{32}$-inch) class. The 1.59-mm diameter class, for instance, included all seedlings with a root collar diameter between 1.19 mm ($^{3}/_{64}$ inch) and 1.99 mm ($^{5}/_{64}$ inch). Culls were defined as those trees in the 1.59-mm ($^{2}/_{32}$ inch) or 2.38 mm ($^{3}/_{32}$-inch) classes (actual root collar diameter less than 2.8 mm or $^{7}/_{64}$ inch).

Results and Discussion

Seedbed densities were very similar each year between the two seeders (table 1) and, with the exception of the single-family lot in 1989, closely represented typical stocking for the nursery during the years involved. The 1989 single-family lot had a density much lower than desired.

The cull percent was not consistently improved with the use of the precision seeder. Cull percent with the precision seeder was actually .6 percentage points higher in 1988 and in the 1989 bulk seedlot and 2.9 and 1.1 points lower, respectively, in the 1989 single family seedlot and the 1991 study.

The 1988 study, a preliminary experiment, involved only two nursery seedbeds, each 61 m (200 feet) long. Average root collar diameter was slightly larger in the bed sown with the Whitfield seeder (table 1), even though bed densities were the same. This could well be a bed effect (a possible difference in fertility, speed of germination, depth of coverage, or another factor) rather than a seeder effect. In the 1989 bulk seedlot and the 1991 study, which involved 3 and 6 pairs of beds, respectively, average root collar diameters were the same. The 1989 single-family seedlot also involved 3 pairs of beds, but average diameter was slightly larger for the precision seeder. Perhaps the lower than normal bed densities found at this location improved the performance of the precision seeder.

Table 1—*Comparison of seedbed densities, mean root collar diameters, and cull percentages for the Whitefield drill-type and Love vacuum-drum precision seeders*

Seeder type	No. of samples	Seedling density		Mean diameter		Cull percent
		m^2	ft^2	mm	32nds inch*	
1988						
Drill	10	364	33.8	4.4	5.6	1.5
Precision	10	364	33.8	4.3	5.4	2.1
1989 bulk						
Drill	18	287	26.7	4.5	5.7	3.3
Precision	18	305	28.3	4.5	5.7	3.9
1989 single-family						
Drill	6	191	17.7	4.5	5.7	5.7
Precision	6	191	17.7	4.7	5.9	2.8
1991						
Drill	24	284	26.4	4.6	5.8	2.8
Precision	24	281	26.1	4.6	5.8	1.7

*Values are thirty-seconds of an inch, e.g., 5.9 is almost 6/32 inch.

The most valuable comparison of the seeders' relative worth, however, is the resulting seedling diameter distribution or uniformity. By distributing seed more evenly by accurate individual placement, the precision seeder is designed to produce a more narrow bell-shaped curve, with fewer very small or very large seedlings. This pattern was not consistently exhibited in this study. Overall, root collar diameter distributions were similar for the two different machines in all 3 years (figure 3). In the 1988 study, the distribution is shifted to the right for the drill-type seeder because of the slightly larger average root collar diameter achieved with that machine, but the curve shapes are similar. For the same reason, the 1989 single-family lot exhibits a shift to the right for the precision seeder, with similar curve shapes. In the 1989 bulk seedlot and the 1991 study, the curves for the two machines are practically identical.

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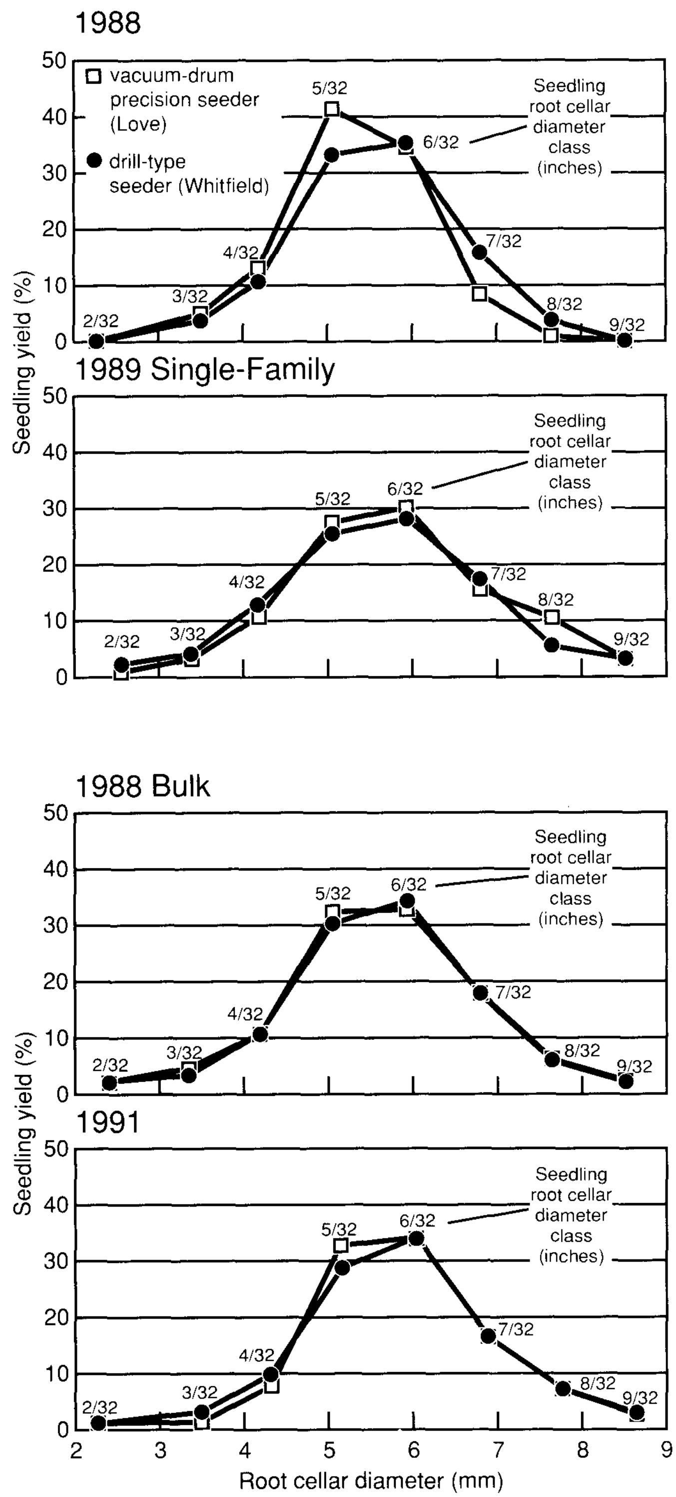

Figure 3—*Root collar diameter distributions for the 1988, 1989, and 1991 installations.*

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Missoula Technology and Development Center's Nursery and Reforestation Programs

Dick Hallman

Program leader, USDA Forest Service, Missoula Technology and Development Center Missoula, Montana

The Missoula Technology and Development Center (MTDC) evaluates existing technology and develops new technology to ensure that nursery and reforestation managers have appropriate equipment, materials, and techniques for accomplishing their tasks. Projects underway at MTDC for fiscal year 1992 are described, and recent publications, journal articles, audiovisuals, and drawings are listed. Tree Planters' Notes 43(3):97-104: 1992.

For more than 20 years the Missoula Technology and Development Center has provided improved equipment, materials, and techniques in site preparation, planting, thinning, and tree improvement for resource and nursery managers. MTDC's work has improved efficiency and safety. Current work is summarized in this report. Under the leadership of Dick Hallman, program leader, the center evaluates existing technology and develops new technology. Projects are funded by the USDA Forest Service's Washington Office Timber Management Staff and priorities are set by the Forest Regeneration Committee, which is made up of representatives from various levels of the Forest Service.

Hardwood Scarifier
(project leader--Dick Karsky)

Natural regeneration of hardwood stands in the Eastern United States has become more common as Forest Service management direction has shifted towards more partial cutting. This has dictated a need for improved tools and techniques to assure timely and adequate regeneration of desired hardwoods.

Many commonly used scarification techniques do not effectively eliminate competition from undesirable vegetation. Bulldozer blades often disturb too much of the ground cover, allow soil moisture to be lost, and encourage erosion. Brush blades, on the one hand, create furrows that help hold moisture, but they do not adequately eliminate competing vegetation. MTDC worked with the Salmon National Forest in Idaho to develop a satisfactory scarifier. The Salmon blade produces a series of furrows that catch and hold moisture and seed while effectively eliminating unwanted vegetation and scattering slash. MTDC also developed an inexpensive anchor chain scarifier. This unit is a modification of the British Columbia drag scarifier developed by the BC Ministry of Forests. MTDC added heavier chain to achieve better disturbance of the soil and improved break-up of slash material.

Both pieces of equipment were tested on the Chequamegon and Nicolet National Forests and found to provide adequate scarification for natural regeneration in a partially cut hardwood canopy. Fabrication drawings are available for both scarifiers from MTDC.

Pollen Equipment
(project leader--Debbie O'Rourke)

About 30 years ago, the Forest Service launched an expanded tree improvement program. A network of genetically superior tree seed orchards was created in an effort to produce top-quality seed. Now that the trees in these orchards are in the cone-bearing stage, the problem of protecting the genetic quality of the seed is of prime importance.

Stands of timber surrounding these orchards are sources of "outside" pollen that could dilute seed quality. It is estimated that up to 40% of the seed now produced in some orchards could be the result of fertilization by this "outside" pollen. Equipment and methods to control orchard pollination are essential to the seed improvement program. MTDC is working with Forest Service Research personnel to develop equipment for mass collection of pollen and mass application of pollen to receptive female flowers.

A vacuum collection system has been developed that gives orchard managers a means of collecting a large supply of pollen from the crown of designated trees in a quick and efficient manner. This pollen is then cleaned and stored for later application to the target trees during the optimum receptive period.

MTDC also has modified a tractor-mounted air duster that can blow collected pollen high into the crown of orchard trees.

This equipment can help protect the genetic quality of orchard seed by insuring genetically acceptable pollen and adequate pollen supplies for increased orchard productivity. Systems have been developed for Douglas-fir and loblolly pine. A final report with drawings and specifications will be prepared when the project is finished in FY 1993.

Reforestation Technical Service
(project leader--Dick Hallman)

Through this continuing project, MTDC personnel provide a variety of services to field units. Services include conducting surveys to determine current reforestation field problems and translating those problems into projects in our program. The technical service project allows us to investigate promising new techniques and equipment that, after evaluation, may become part of the Forest Service inventory of equipment. In addition, Reforestation Technical Services provides a forum for answering inquiries from field personnel concerning equipment, materials, and techniques applicable to reforestation activities.

Papers presented at professional meetings, technical reports, and drawings are funded through this project. Current work includes

?? A new edition of the Reforestation Equipment Catalog
?? Improved hand-planting tools
?? Drawings of a seed orchard netting retrieval system
?? Applying global positioning system (GPS) handheld equipment for vegetation mapping in a Forest Service International Forestry project to help Sudan in its efforts to stop the desertification of its land.

Portable Power Platform
(project leader--Keith Windell)

An off-road vehicle that both transports equipment and materials and provides a lightweight power source for operating a variety of implements and hand-held tools has been assembled at MTDC. The vehicle selected for this system is the Iron Horse, manufactured in Sweden.

In a service-wide survey conducted by MTDC in 1986, Forest Service personnel placed a high priority on the need for a portable power source. They asked for an off-road vehicle capable of operating safely on a 35% grade and that could be operated by a non-riding operator, walking behind the machine, and power accessories that could be powered either by direct drive or electrical generation.

The Iron Horse met all these criteria. It is a tracked vehicle that weighs 878 pounds when an empty steel cargo carrying platform is attached. It is powered by a four-stroke 5-horsepower Honda gasoline engine and is operated from a non-riding position by means of a steering arm. The basic unit is rated to carry 1,100 pounds.

MTDC conducted an evaluation of the Iron Horse that focused primarily on its load carrying and terrain capabilities and the safety aspects of its field operations. The unit proved to be safe and maneuverable. MTDC designed a bulk load carrying platform and a multi-purpose hydraulic power pack and tested them in FY 1990. The hydraulic unit is powered by an 18-horsepower gasoline engine. A variety of tools for pruning, thinning, and chipping have been tested with the unit. MTDC is working with a prototype spot-site scarifier that mounts on the power platform. This scarifier was tested on two sites in spring 1992 and drawings will be available in early 1993.

Bracke Scarifier
(project leader--Dick Karsky)

MTDC was asked to modify the Bracke scarifier seeder to improve its performance when direct seeding sand pine. A pneumatic seeder and visual seed-monitoring system were added to the unit. The seeder distributed the seed out along the scalp and delivered 8 to 10 seeds per scalp. Drag chains were added for better seed coverage along with a packing wheel designed to firm up the soil over the seeds. Early indications are that the improvements can substantially increase seed germination and improve stocking distribution.

MTDC also modified the British Columbia drag chain scarifier as an alternative to the Bracke scarifier/ seeder for seeding sand pine. This piece of equipment was configured with three equally spaced anchor chain segments of five links each and a gravity-drop tube seeder.

Both the Bracke and the BC drag chain scarifier/ seeders are currently in use on the Ocala National Forest in Florida.

Field Storage
(project leader--Diane Herzberg)

A long-standing problem in reforestation has been the lack of adequate seedling storage facilities. A proper facility must be able to keep a good supply of fall seedlings at a cool temperature to maintain their dormancy. To be especially useful, this facility should be portable, and in some cases have its own power supply. MTDC was assigned the task of coordinating development of a temperature controlled portable storage facility that could be easily moved to field locations. Two pickup truck-sized transportable refrigeration storage units are the result of this effort.

Polar Products of Torrance, California, offers a portable pickup-sized temperature-controlled unit for use as a seedling cooler. The 12-V refrigeration system operates from the vehicle's electrical supply or a photovoltaic array with a backup battery. The system can also be run on 110-V ac through a battery charger.

MTDC has developed a slide-in pickup-sized storage unit that relies on standard commercially available refrigeration components and operates on a 110-V ac current. This unit was designed to complement the 12-V dc Polar Products system.

Seedling Protection
(project leader--Keith Windell)

MTDC has been working with Southern Region Timber Management to evaluate commercially available devices that can be used to protect seedlings from animal damage and promote growth (figure 1). Tree shelters, which were developed in England, are tall plastic tubes used to increase seedling growth and survival rates. They protect seedlings from animal browsing and enhance the microclimate around the seedlings. With current increased emphasis on ensuring the survival of selected hardwood species, tree shelters may be helpful in maintaining and re-establishing hardwoods on difficult planting sites. Tree shelters are currently being used at scattered locations throughout the United States, mostly on an experimental

Figure 1—*Seeding protectors promote new growth.*

basis. Long-term benefits have yet to be determined. MTDC has examined field requirements, costs, and logistical problems. An extensive literature search has been completed and a publication documenting this preliminary work is available on request.

Steep Slope Site Preparation
(project leader--Dick Karsky)

At present, mechanical site preparation equipment is generally restricted to slopes of less than 35%. With the emphasis on "ecosystem management" in the Forest Service, more residual material is being left after timber harvests. New methods are needed to adequately treat brush and logging debris and to prepare planting sites on slopes of more than 35% with heavy slash.

In late FY 1991, a guidance group from the Forest Service's Northern, Pacific Southwest, and Pacific Northwest Regions met with MTDC engineers to develop a strategy to solve this problem. MTDC has conducted a market and literature search seeking equipment and techniques currently available for steep slope work, and a report is being prepared. All applicable equipment from large excavators to small 4-wheel-drive ATV's will be considered for Forest Service tasks. MTDC will continue to monitor activities in steep-slope site preparation.

Mulch For Seedlings
(project leader--Keith Windell)

Ground mulch is commonly used in the ornamental and landscape business to reduce vegetative competition and improve soil moisture around newly planted trees and shrubs. A preliminary investigation by Forest Service researchers indicates that ground mulch can significantly improve survival and promote the early growth of seedlings on National Forest System lands.

MTDC personnel met in early FY 1992 with a guidance group of Forest Service timber management experts to determine the course of this investigation. Data on various types of mulch material, current techniques, and equipment for placing and stabilizing the material around newly planted trees is being collected. Preliminary information should be gathered and presented to the guidance group in December 1992.

People In Tree Tops
(project leader--Tony Jasumback)

Timber Management personnel have for many years expressed the need to gain access to the top portions of trees for various cultural works such as pollination, cone collection, and insect and disease surveys. The tree climbing equipment commonly used is dangerous and provides only limited access to the entire crown. Mechanical equipment such as lifts require frequent moving to reach all sections of a tree crown and are limited in the heights they can reach.

MTDC personnel have begun an investigation of available equipment and techniques that may be applicable to tree crown work. Lighter-than-air craft and new highly mobile lifts (figure 2) are two possibilities that will be examined. MTDC is working with Southern Region Timber Management personnel to develop an approach to this problem.

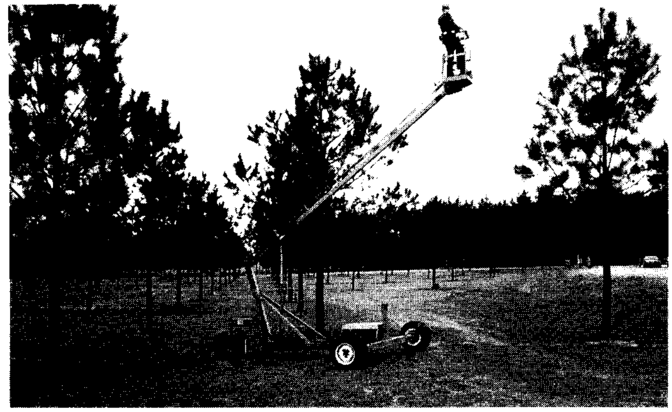

Figure 2—*Highly mobile lifts make tree crown work more convenient and safer.*

Seedling Counter
(project leader--Dave Gasvoda)

To meet the demand for seedlings for national reforestation efforts, Forest Service nursery managers need accurate cultural and inventory data. Most data can be collected only by employing crews of counters to sample each bed in a nursery and statistically determine the quantity of seedlings.

MTDC was asked to develop a method of inventorying nursery seedlings without resorting to costly hand counting. An automated tree seedling counter was developed. This counter uses an infrared light beam to detect and count seedlings as the unit is moved along a planted row in the nursery. All components of the counter are mounted on a steel frame that attaches to a tractor with a category 1 three-point hitch.

A transmitter emits a beam of light across and through the seedling row to a receiver. The beam shape, a vertical plane of light, makes it possible to distinguish seedling stems from branches. Nearly vertical stems will block the beam, while branches crossing at an angle will block only a portion of the plane of light and not register as a count. Because stems are not always vertical and branches or needle masses sometimes are large, beam height and width must be selected carefully for the species and size class to obtain optimum accuracy. In tests conducted at eight Forest Service nurseries, the MTDC seedling counter worked well, with the majority of species. Count accuracies are well within the design criteria of ± 10%. Most counts have been within ± 5%.

Two seedling counters are now in use at Forest Service nurseries. Since a commercial source has not yet been established, six additional units have been fabricated at MTDC shops in FY 1992 and installed in Federal nurseries.

Machine Vision
(project leader--Dave Gasvoda)

Forest Service tree nurseries tailor their seedlings to the specific needs of national forests and ranger districts. In doing so, these nurseries must have effective quality control. Currently, lifted seedlings are delivered to packing sheds for grading and packing. In this process, graders sort seedlings by hand, cull the unacceptable plants, and sort the others by stem diameter, top length, root area, and overall quality. They then place the acceptable seedlings on a packing belt for final processing and packaging. Quality control checkers further monitor this operation by picking samples and overseeing grader performance. This is a labor-intensive, expensive process.

MTDC was asked to automate the quality control and grading in an effort to reduce costs. Under contract to MTDC, Oklahoma State University investigated the feasibility of using machine vision in grading and quality control operations. Machine vision and image processing were used to measure morphological properties of seedlings. A grading program was integrated into the computer software to accept or cull each seedling according to the morphological criteria. This system proved itself in initial testing. Oklahoma State University is working with Oklahoma and Oregon State nurseries and the Forest Service to further refine this technology.

A machine vision system utilizing a "line scan" system is now being developed by Oklahoma State University to measure and record seedling morphological characteristics (figure 3). This system promises increased efficiency in quality control for the Forest Service nursery manager. This system was successfully demonstrated at the Elkton State Nursery, Oregon. Plans for developing a production model are being made.

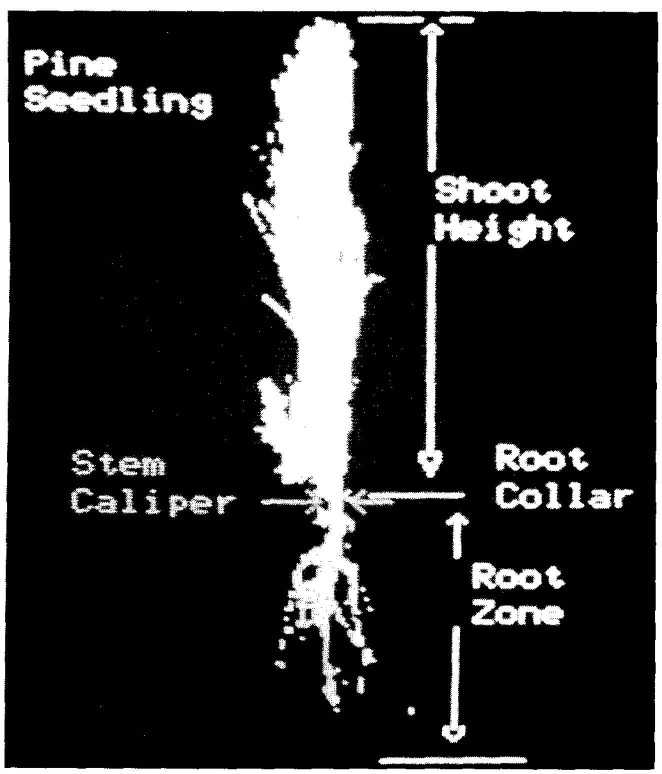

Figure 3—*Machine vision images measure morphological properties of seedlings.*

***Isozyme* Laboratory**
(project leader--Debbie O'Rourke)

The National Forest Genetics Electrophoresis Laboratory (NFGEL) was established by the Forest Service in 1988 for starch gel testing of forest plant material. Because existing equipment was not designed for use on a production basis, problems with efficiency were immediately evident. MTDC was asked to identify the problems and design an effective system for production rather than research.

MTDC engineers with the help of NFGEL geneticists clarified the problems and designed an integrated system of equipment that included grinding blocks, wick combs, and jigs for sample preparation; buffer trays and gel molds for enzyme separation; and a gel slicer to slice the gel. Prototypes were built and test runs with the system were successful. NFGEL has found the greatest advantage in the gel molds and buffer tray. As a result of the MTDC designs, test results are clearer and preparation time has been greatly reduced. Use of this equipment has helped the lab to double its production.

The development of this equipment has increased both the quality and efficiency of the starch gel testing operation. The test project was completed in FY 1991. MTDC has fabricated twelve additional trays and molds in FY 1992.

Progeny Test Seeder
(project leader--Diane Herzberg)

Forest Service nurseries sow beds with highvalue tree improvement seed to meet special requirements of geneticists. Spacing and sowing specifications have dictated a hand planting operation for the exact placement of these seeds.

The progeny test seeder was developed at MTDC to place progeny tree seed in exact sowing patterns in bareroot nurseries. This seeder is an alternative to the labor-intensive plywood board sowing method currently used. The seeder is a four-wheel operator-propelled (pedal-powered) vehicle that can be used either indoors or out of doors.

The machine was designed to straddle a 48-inch-wide nursery bed. It is an 8-row sowing machine with 12 drop tubes in each row. This allows the seeder to sow 96 seeds simultaneously. The seeds are released from pre-filled shutterlike seed trays to drop down a set of tubes to the nursery bed below. This allows the operator to accurately position the seed in the desired plot. Seed covering was not designed into the unit, however. The seeds must be covered with dirt or grit by hand or with a spreader.

Root Pruner
(project leader--Debbie O'Rourke)

Tree seedlings are pruned in the packing shed to provide seedlings with a uniform root length. This is currently done with hand-operated office-type paper cutters. This system has a number of problems. The hand cutting is difficult, and workers tire quickly. They are subject to carpal tunnel injury and finger lacerations. The work goes slowly and typically, additional personnel and equipment are required to keep up with production. Also, contractors have difficulty meeting Forest Service root length specifications.

MTDC was asked to develop a root pruner prototype that would automate this process and increase packing shed safety and efficiency. Early in developing the prototype, MTDC engineers decided that a small conveyor, separate from the grading line, would be used to present the tree bundles to the cutter. This would keep the operator a safe distance from the blade. The small conveyor would also be more easily adapted to most existing packing sheds.

The next design consideration was to select the method of cutting the roots. Lasers and high-pressure water jets were cost prohibitive and rotary saws were noisy and shattered the root ends. The solution was found in a pneumatic shear. The power source, compressed air, was readily available in the packing shed. The quality of the cut was excellent, and simple electric controls would allow the remote activation desired for improved safety.

The prototype MTDC developed accommodates up to an 8-inch diameter seedling bundle and carries them to the cutting area on plastic conveyor chain (figure 4). When these bundles enter the cutting area, the shear is activated and the seedlings are pruned to the correct length. The bundles are then transported to the end of the unit and packed in boxes. The cutting area is completely enclosed with a Lexan guard, which provides a barrier between the operator and the cutting mechanism, yet still allows the necessary visibility.

Initial testing has been promising. The pneumatic shear produces a clean cut. The conveyor is simple to operate, and output easily matches grading line production. Further refinements will be made and the project is scheduled for completion in FY 1993.

Figure 4—*Prototype root pruner has been tested at the Forest Service's Coeur d'Alene Nursery.*

Seedling Box Lifter
(project leader--Dick Karsky)

A 1984 survey of Forest Service nursery managers indicated that an improved method of lifting seedling boxes from the ground to transport trailers was of a high priority. They cited the problems of labor costs and the high probability of back injuries. A prototype was designed and built by MTDC engineers. Initial tests were conducted at the Coeur d'Alene, Lucky Peak, and J. Herbert Stone Nurseries.

The seedling box lifter is adaptable to either side of a standard farm tractor. It attaches to the tractor's three-point hitch and allows the tractor to also pull the transport trailer.

A frame mounted on the side of the tractor with a lift cylinder attached raises and lowers the front of the pickup unit. The pickup unit grabs the boxes and positions them on the elevator chain. This elevator chain raises the boxes to a height of 3 to 4 feet above the trailer bed and delivers them to an inclined gravity conveyor which then moves them to the center of the trailer. Stackers or box handlers then stack the boxes in the appropriate place on the trailer. The belt/chain assembly can be adjusted to pick up boxes from 14 to 19 inches wide. It can typically deliver 10 to 12 boxes per minute to the trailer and does an excellent job with both plastic and corrugated boxes.

This project has been terminated. To develop a complete pickup system that integrates a trailer/ transport system into the box lifter operation requires further work, which would require further funding.

Smart Toolbar
(project leader--Ben Lowman)

Nursery equipment operators have experienced problems in maintaining toolbar height at a consistent level above the seedbed while doing various cultural operations. This capability is essential for such tasks as root wrenching, root culturing, and top pruning. With current technology, it is possible to design a system that can automatically sense toolbar height above the seedbed and simultaneously adjust a toolbar to maintain whatever level is desired. Essentially, the goal of this project is to test various distance sensing devices, determine the most applicable device, and design a toolbar system for automatic height control. Initially this idea originated at the J. Herbert Stone Nursery and MTDC will be working with them on this project. The project began in October 1991. Ultrasonic measuring devices were tested in FY 1992 and results showed problem areas; modifications were made and retested. Further testing is planned.

Seed Separator
(project leader--Ben Lowman)

Forest Service nurseries are currently reporting difficulties in separating pitch from tree seed. This is especially true with white pine and western larch seed. Many seed separation devices used in agriculture are not presently being used in tree seed cleaning operations. Initial testing and consultation with Bob Karrfalt, Director of the National Tree Seed Laboratory in Macon, Georgia, revealed that a vibratory separator showed the most promising capability of separating pitch from seed. MTDC has purchased a small vibratory separator and tested it at Coeur d'Alene and Lucky Peak Nurseries. Further tests and demonstrations are planned.

Nursery Technical Services
(project leader--Dick Hallman)

In the past, this project has allowed MTDC to provide technical services to Forest Service nurseries. A newly funded aspect now also allows MTDC to provide limited engineering consultation services to State and private non-industrial organizations that produce forest tree seedlings for reforestation. New applicable technology is continually monitored under this project and MTDC personnel disseminate this information by presenting papers at professional meetings and symposia. They also answer inquiries from Forest Service field personnel, visit various Forest Service Nurseries, and provide drawings and publications on request.

Recent accomplishments

1. Modification and fabrication of small root growth chambers for Forest Service Research laboratories and nurseries.
2. Production of fabrication drawings for the gravity table for reverse flow designed by the L.A. Moran Regeneration Center (California Division of Forestry) at Davis.
3. Production of fabrication drawings for a new mulch spreader designed and built by the Forest Service's J. Herbert Stone Nursery at Medford, Oregon.
4. Modification of a Fobro tree harvesting combine for the Forest Service's Wind River Nursery to reduce downtime and increase efficiency.
5. Production of the Nursery Equipment Catalog.