Comments

Tree Planters' Notes
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Cover: Fall colors on the Sawtooth National Recreation Area (FS photograph by Jim Hughes).

Reinvention Hits *TPN*

Reinvention seems to be the order of the day for Federal, State, and local agencies, as well as for private companies. Organizations need reinvention in order to respond to change-the one constant we can rely on. My duties at the USDA Forest Service are varied, and editing TPN is only one of many. New imperatives constantly arise that must be dealt with, and one of them is the issue of sustainable development. In 1987, the World Commission on Environment and Development issued the "Bruntland Report," which defined sustainable development as "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs."

This issue is becoming a high priority for the Forest Service, and the agency has formed a 6-person team to work on it full time. Its primary duty will be to help institutionalize the concept of sustainable development in the Forest Service: sustainable forest management is a primary component of sustainable development. I have been chosen for the team, and I'm looking forward to joining it. The team's assignment will last about 18 months, but because its duration is uncertain, we have decided at ***TPN*** to make some changes in how things are done.

Producing ***TPN*** is a real team effort. We on the editorial board take a team approach to garnering new authors and handling the review process. We have decided to work even more as a team in handling the ***TPN*** work load.

One of the Forest Service's reinvention initiatives is to merge the role of its Washington Office with the roles of various regional offices. Rebecca Nisley, currently our managing editor, will become new editor-in-chief. She will work closely with our newly expanded editorial board in putting out the journal. I am remaining in the Washington Office and will continue to help coordinate production. Clark Lantz will assist Rebecca in technical matters, as will other members of the board. If you have questions or concerns regarding editorial policy, you should turn first to Rebecca or Clark.

We are confident that these changes will ensure smooth delivery of the same highquality journal to you, the readers. As always, if you have comments on these changes or any other aspects of ***TPN***, please give any of us on the board a call.

In departing as editor-in-chief (although I will still be around), I would like to say how much I've enjoyed working on TPN. It has been truly satisfying for me, and I have thoroughly enjoyed dealing with all of the authors and hearing from you, the readers. I hope that TPN has contributed, if only in some small way, to improving reforestation in this country and around the world.

Thanks for the wonderful opportunity!

Robert Mangold
Editor-in-Chief
Cooperative Forestry
USDA Forest Service
Washington, DC

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Early Survival and Growth of Loblolly Pine Seedlings Treated With Sulfometuron or Hexazinone Plus Sulfometuron in Southwest Arkansas

J. L. Yeiser and E. J. Rhodenbaugh

Professor and research specialist, School of Forest Resources and Arkansas Agricultural Experiment Station University of Arkansas, Monticello, Arkansas

Improved survival and growth of pine (Pinus *spp.*) *seedlings have been observed as a result of herbaceous weed control with sulfometuron, hexazinone, or combinations of the two herbicides. In this study, survival and growth of planted loblolly pine* (Pinus taeda *L.*) *seedlings were assessed two growing seasons after treatment with seven selected rates of hexazinone (1.12, 0.84, 0.75, 0.56, 0.37, 0.28, and 0 kg ai/ha) mixed with 0.10 kg ai/ha sulfometuron and compared to values for untreated (control) seedlings. Treatment with hexazinone– sulfometuron mixtures resulted in greater height and diameter growth than treatment with sulfometuron alone. All seven herbicide treatments resulted in improved survival and increased growth compared to values for untreated seedlings two growing seasons after treatment. Height and diameter growth were greatest with 0.84 kg ai/ha hexazinone mixed with 0.10 kg ai/ha sulfometuron. However, increasing the rate of hexazinone above 0.56 kg ai/ha did not substantially increase growth, indicating that 0.56 kg ailha hexazinone plus 0.10 kg/ha sulfometuron may be the best choice operationally.* Tree Planters' Notes 45(4):116-120; 1994.

Herbaceous weed control has enhanced survival and growth of newly planted loblolly pine seedlings *(Pinus taeda* L.) throughout the South (Nelson and others 1981, Knowe and others 1985, Zutter and others 1986, Creighton and others 1987, Miller and others 1991). Sulfometuron (Oust®) and hexazinone (Velpar® L) have proven to be effective, either alone or in combination, for controlling herbaceous competition about recently planted pine seedlings, resulting in increased survival and growth (Michael 1985, Cantrell and others 1985, Yeiser and Boyd 1989). (Hexazinone is 3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione and sulfometuron is {methyl 2-[[[[(4,6dimethyl-2 pyridmidinyl) amino] carbonyl] amino] sulfonyl] benzoate} .) Early growth increases have been projected into substantial economic gain at the end of a rotation, making investment in herbaceous weed control with either sulfometuron or hexazinone an attractive silvicultural alternative (Atkins 1984, Anderson and others 1986, Busby 1992).

Sulfometuron controls a variety of forbs and grasses but does not control brush or hardwoods. Hexazinone at selected rates has the added advantage of controlling brush and hardwood as well as a variety of herbaceous species (Atkins 1984, Gonzalez 1985, Michael 1985, Anderson and others 1986). In previous studies, sulfometuron-hexazinone mixtures reduced herbaceous competition and stimulated loblolly seedling height and diameter growth above that observed in untreated plots when herbaceous cover was heavy (Yeiser and Boyd 1989) and in a newly planted old field in northern Arkansas (Gardiner and Yeiser 1993). Metcalfe (1985a) reported improved early growth and survival resulting from herbaceous control with sulfometuron and hexazinone mixtures at sites in Kentucky and Virginia. The early growth increment observed in loblolly pine seedlings in these studies points to the need for further examination of sulfometuron-hexazinone combinations for weed control in newly planted pine plantations. Consequently, the objectives of this study were to assess survival and growth responses of loblolly pine seedlings to selected rates of hexazinone mixed with a constant rate of sulfometuron and the costs of treatment.

Methods

The study site is in Miller County near Fouke, Arkansas. The study was established on a poorly drained, mixed pine-hardwood flatwood site that had been recently harvested and the slash wind-rowed and burned prior to bedding. Soils at the site were Wrightsville silt loams, which are deep, poorly drained soils capable of supporting mixed pine-hardwood forests (Laurent 1984). The site index for loblolly pine was 24 m at age 50. Four blocks were established at the site with eight plots in each block. A total of 20 seedlings in two 10-seedling rows were hand-planted on the crest of beds in each plot with 3.05 m between rows and 2.4 m between seedlings in a row. Two rows were planted around the perimeter of the study to serve as a border. Seedlings were hand-planted in February 1987.

Treatments consisted of (1) seven selected rates of hexazinone— 1.12, 0.84, 0.75, 0.56, 0.37, 0.28, and 0 kg of active ingredient (ai)/ha— mixed with 0.10 kg ai/ha sulfometuron and (2) an untreated control. Herbicides were applied in 0.91-m bands, centered over the top of seedling rows, in early April 1987. Herbicides were applied at a rate of 140 L/ha with a two-nozzle handheld CO_2 -pressurized backpack sprayer.

Seedling heights (centimeters) and groundline diameters (gld in millimeters) were measured immediately after planting and at the end of one and two growing seasons. Percentage survival was calculated following the first and second growing seasons by dividing the number of surviving seedlings by the number of seedlings originally planted in each plot. Height and gld growth for each surviving seedling were calculated by subtracting measured height and gld of the previous year from measured height and gld of the current year. For example, first-year height growth was the height measured after one growing season minus initial height; second-year height growth was the height measured after two growing seasons minus first-year height; and total height growth was the second-year height minus the initial height. The same calculations were carried out for gld values.

Herbicide costs were obtained from 1993 prices supplied by a representative of the manufacturer. Prices were given in dollars per ounce (sulfometuron) or gallon (hexazinone) and converted to dollars per hectare. Height and diameter growth per herbicide dollar (centimeter or millimeter per $, cm or mm / $*haG1 were calculated by dividing the total height or gld growth by the dollars per hectare spent on the individual herbicide treatments.

Regression analyses for height and diameter growth were conducted for the continuous variable hexazinone rate. Percentage survival data were transformed with arcsin % %. Real numbers for percentage survival are presented in this paper. Survival and costs were analyzed with analyses of variance according to a randomized complete block design. Means were separated with Duncan's multiple range test. Effects were considered significant at the 0.05 probability level.

Results and Discussion

Survival. Hexazinone rate significantly affected first- and second-year survival (table 1). Percentages and significance levels for second-year survival were nearly identical to first-year survival (with the only exception a 2.5% decrease for 1.12 kg ai/ha hexazinone +0.10 kg ai/ha sulfometuron); therefore only secondyear survival will be discussed. Survival was 80% or greater for treated plots and averaged 75% for the untreated check. The addition of hexazinone, regardless of rate, did not significantly improve survival over that observed for sulfometuron alone. However, all four middle hexazinone rates plus 0.10 kg ai/ha sulfometuron and 0.10 kg ai/ha sulfometuron with no hexazinone significantly improved survival over untreated seedlings. Survival decreased more than 11% when 1.12 kg ai/ha hexazinone was added to the 0.10 kg ai/ha sulfometuron. Other studies have also reported increased pine seedling mortality resulting from application of 1.12 kg ai/ha hexazinone (Metcalfe 1985b), indicating that this level may be harmful to young loblolly pine.

Hexazinone rate-growth relationship. Significant quadratic relationships were delineated for all growth parameters except first-year diameter growth (table 2). Total height or gld growth, which is height or gld following two growing seasons minus initial height or gld, reflects the trends noted in first- and second-year growth. For this reason, the following discussion will be limited to total height and diameter growth. First-

Table 1-*Survival of hand-planted loblolly seedlings 2 years after treatment with hexazinone and sulfometuron (kg ai/ha) for herbaceous weed control in southwest Arkansas*

Pesticide treatment (kg ai/ha)		%
Hexazinone	Sulfometuron	survival
1.12	0.10	80.0 cd
0.84	0.10	96.3 a
0.75	0.10	93.8 ab
0.56	0.10	91.3 abc
0.37	0.10	91.3 abc
0.28	0.10	86.3 bcd
0.0	0.10	91.3 abc
0.0	0.0	75.0 d

Note: Means within a column sharing a letter are not significantly different (Duncan's multiple range test, P # 0.05).

and second-year growth will be included in figures 1 and 2 but will not be discussed.

Total height growth increased significantly two growing seasons after treatment on plots treated with hexazinone (figure 1). Total height growth averaged about 53 cm for untreated seedlings (data not shown) and about 65 cm for sulfometuron alone (the 0 hexazinone rate in figure 1).

Height growth following two growing seasons peaked at 0.84 kg ai / ha hexazinone (figure 1); however, height growth from 0.56 to 0.84 kg ai / ha hexazinone was similar, varying by 0.7 cm (figure 1). Height growth declined sharply between 0.84 and

Table 2-*Regression of first-year, second-year, and total height and groundline diameter (gld) growth for the continuous variable hexazinone rate*

Growth variable	b_0	b_1	b_2	R^2	Pr>ITI
Height (cm)					
First-year	18.46	26.85	-18.69	0.88	0.01
Second-year	43.32	72.88	-60.67	0.86	0.01
Total	61.77	99.73	-79.35	0.89	0.01
Diameter (mm)					
First-year	5.18	2.10	-1.56	0.31	0.32
Second-year	9.59	11.13	-7.37	0.86	0.01
Total	14.77	13.23	-8.93	0.84	0.03

Note: Sulfometuron at 0.10 kg/ha was included in all applications of hexazinone. Data included in the table are intercept (b_0), slope of the linear portion (b_1), slope of the quadratic portion (b_2), coefficient of determination (R^2), and the significance level (Pr>ITI). First-year = height or gld following first growing season minus initial height or gld; second-year = height or gld following second growing season minus height or gld following first growing season; total = height or gld following second growing season minus initial height or gld.

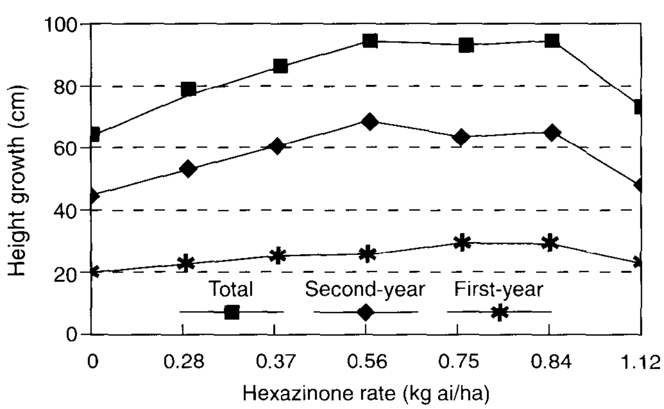

Figure 1—*Height growth from initial through the first growing season (**first-year**), from the first through the second growing season (**second year**), and from initial through the second growing season (**total**) for the continuous variable hexazinone rate. Sulfometuron at 0.10 kg ai/ha was included in all applications of hexazinone.*

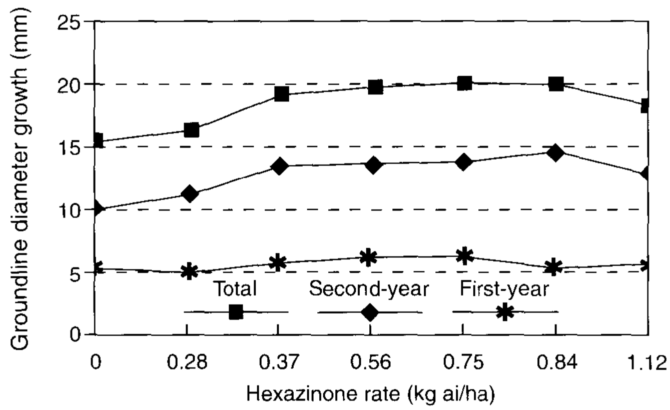

Figure 2—*Groundline diameter growth from initial through the first growing season (**first-year**), from the first through the second growing season (**second year**), and from initial through the second growing season (**total**) for the continuous variable hexazinone rate. Sulfometuron at 0.10 kg ai/ha was included in all applications of hexazinone.*

1.12 kg ai / ha hexazinone, indicating that hexazinone application rates greater that 0.84 kg ai/ha may be harmful to seedlings.

Diameter growth for untreated seedlings averaged 12.6 mm from planting through the second growing season after treatment (data not shown). Sulfometuron with no hexazinone increased gld growth after two growing seasons by about 3.3 mm (the 0 hexazinone rate in figure 2) but was not significant when compared to untreated seedlings.

Diameter growth two growing seasons after treatment also peaked at the 0.84 kg ai/ha hexazinone rate (figure 2). Diameter growth was, however, nearly level from 0.37 to 0.84 kg ai/ha hexazinone, varying by 0.8 mm (figure 1). As with height growth, diameter growth declined from 0.84 to 1.12 kg ai/ha, although the decline was not as steep as observed for height growth.

These results indicate that the optimal rate of hexazinone mixed with 0.10 kg ai / ha sulfometuron would be 0.84 kg ai/ha. However, given that height and diameter growth did not substantially increase from 0.56 to 0.84 kg ai / ha, hexazinone added at the 0.56 kg ai/ha rate may be the more appropriate treatment for operational use. In addition, hexazinone is sensitive to soil texture, and rates may need to be increased on sites with fine-textured soils (Michael 1984, Gonzalez 1985). Another consideration is the sulfometuron application rate. The rate used in this study was less than the current recommended rate of 0.13 kg ai / ha (2 oz / acre product). Increasing sulfometuron to the recommended rate may allow a reduction in the hexazinone rate. On the other hand, hexazinone is less expensive than sulfometuron and it could prove more economical to use 0.10 kg ai/ha sulfometuron with 0.56 kg ai/ha hexazinone rather than increasing concentrations of sulfometuron and decreasing the hexazinone rate.

Controlling the herbaceous competition, either with or without hexazinone, clearly improved loblolly seedling survival, height and diameter growth. Other studies have also shown that early herbaceous weed control stimulates pine seedling survival and growth (Nelson and others 1981, Knowe and others 1985, Zutter and others 1986, Creighton and others 1987). Applying sulfometuron or sulfometuron-hexazinone mixtures resulted in increased height growth from about 12 cm to more than 40 cm at the end of two growing seasons after treatment. Early gld growth increases over untreated seedlings ranged from about 2 mm to more than 7 mm following the second growing season after treatment.

Addition of hexazinone resulted in greater height growth two growing seasons after treatment for five of the hexazinone rates and greater diameter growth for the four middle hexazinone rates. These results show that adding hexazinone at rates ranging from 0.37 to 0.84 kg ai/ha to 0.10 kg ai/ha sulfometuron stimulated height and diameter growth relative to sulfometuron with no hexazinone. The question, then, is whether or not the increased early growth observed with hexazinone-sulfometuron mixtures justifies the additional expense of hexazinone.

Economic evaluation of treatments. The true economic value of the selected treatments cannot be assessed after only 2 years. Long-term economic evaluations of herbicide treatments are lacking; however, growth and yield models have projected that increased early growth could allow earlier thinning and reduce the rotation length, improving stand economics (Minogue and others 1991, Busby 1992). Earlier thinning could provide an early return on investment and shortening the rotation length reduces the length of time investments in the stand must be carried. These factors weigh heavily in the final economic evaluation of any treatment. An evaluation of the initial herbicide costs and early growth resulting from investment in these herbicides could provide valuable information as to the level of investment in sulfometuron and hexazinone necessary to produce the desired growth response. The following evaluation cannot be considered as the final indicator of the economic value of the individual treatments, but it serves to highlight the cost and the early growth resulting from the treatments studied.

Herbicide cost for the selected treatments ranged from $5.31 /ha for sulfometuron with no hexazinone to $13.60/ha for 1.12 kg ai/ha hexazinone mixed with 0.10 kg ai/ha sulfometuron (table 3). Growth, both height and diameter, per herbicide dollar was greatest for sulfometuron alone, even though this treatment produced the least height and diameter growth of all treated plots two growing seasons after treatment. Hexazinone at rates of 0.56, 0.37 and 0.28 kg ai/ha showed similar height and diameter growth per dollar (table 3). Once the hexazinone rate exceeded 0.56, growth per dollar began to decline and the least growth per dollar was observed for 1.12 kg ai / ha hexazinone plus 0.10 kg ai/ha sulfometuron.

Conclusions

Survival was improved by all levels of herbaceous weed control. There was no gain in survival by adding hexazinone, and survival did not increase with increased rates of hexazinone. Addition of 1.12 kg ai/ha hexazinone decreased survival, indicating that this level of hexazinone may be harmful to newly planted loblolly pine seedlings.

The optimal rate of hexazinone to include with 0.10 kg ai/ha sulfometuron was 0.84 kg ai/ha based on site conditions prevalent in this study. However, the 0.56 kg ai / ha rate may be more appropriate operationally given that growth was similar from 0.56 kg ai/ha to 0.84 kg ai/ha and the cost of the 0.56 kg ai/ha treatment was less. Factors such as soil type, site index, and the amount and type of herbaceous and woody competition need also be considered when determining the optimal rates of hexazinone and sulfometuron necessary to produce the desired growth response.

Sulfometuron with no hexazinone was the least expensive treatment and produced the most growth

Table 3-Height and gronndline diameter growth two growing seasons after treatment per dollar spent off *herbicide (total height or diameter growth per herbicide cost)*

Pesticide treatment (kg ai/ha)			Height	gld
Hexazinone	Sulfometuron	Cost ($/ha)	(cm/$`ha^{-1})	(mm/$*ha^{-1})
1.12	0.10	13.60	5.13d	1.34d
0.84	0.10	11.53	8.21 c	1.72 c
0.75	0.10	10.88	8.44 c	1.82 c
0.56	0.10	9.46	9.96 b	2.07 be
0.37	0.10	7.87	10.94 b	2.43 b
0.28	0.10	7.38	10.44 b	2.21 b
0.0	0.10	5.31	12.31 a	2.88 a

Note: Means within a column sharing a letter are not significantly different (Duncan's multiple range test. P #0.05).

per dollar spent on herbicide, although this treatment showed the least total height and diameter growth of all the treated seedlings. Long-term evaluation to determine whether the early seedling growth response seen with the addition of hexazinone improved stand economics sufficiently to justify the added expense would be useful.

Address correspondence to J.L. Yeiser, University of Arkansas School of Forest Resources, Box 3468, Monticello, AR 71656.

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Volume Displacement Provides a Quick and Accurate Way To Quantify New Root Production

John T. Harrington, John G. Mexal, and James T. Fisher

Professors, Department of Agronomy and Horticulture, Mora Research Center
New Mexico State University, Las Cruces, New Mexico

Root growth potential (RGP) measurement can be time-consuming and tedious, especially when seedlings have fibrous root systems. A volume-displacement technique involving suspending seedling roots and shoots in a clear plastic tube allows rapid estimation of the volume of plant parts while minimizing gravimetric errors. The technique was tested in three experiments examining (1) the repeatability of the technique, (2) its usefulness in estimating RGP, and (3) the relationship of volume displacement to tissue dry weight. Results indicate that this technique provides a quick, reproducible measure of seedling size while allowing a rapid (2-seedlings-per-minute) assay of RGP in container-grown stock.
Tree Planters' Notes 45(3): 121-124; 1994

Seedling morphological attributes have been used extensively in reforestation research to assess seedling performance potential and to explain outplanting performance (Mexal and South 1990, Mexal and Landis 1990). Nondestructive measures of seedling morphology allow for measurement of the entire test population. This increases the sensitivity of analysis by eliminating the need for subsampling. Traditional nondestructive measures include seedling height, root collar diameter, and (occasionally) total seedling fresh weight. In addition to providing these measures, volume displacement analysis allows total biomass to be subdivided into shoot and root volume. Volume displacement analysis provides sensitive and repeatable morphological information that may be useful in physiological analysis of seedling performance potential (for example, in root growth potential analysis) (Burdette 1979).

There are two approaches to volume displacement analysis. The first approach, actual volume displacement, measures the volume of water displaced when plant tissue is submerged in a vessel of water (Novoselov 1960). The second is a gravimetric approach based on Archimedes' principle, which states that "a body wholly or partly immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced" (Weast 1980). In the gravimetric approach, change in weight is used as the estimate of plant volume. A system for using gravimetric volume displacement is described below (see Materials and Methods).

Volume displacement analysis has the advantage of providing a fast measure of new root production (Burdette 1979). In addition, its nondestructive nature permits repeated measures over time. However, previously published volume displacement techniques have serious limitations. First, techniques that measure actual volume displaced require elaborate glassware configurations if they are to be sensitive enough to detect slight differences in seedling stock. Second, most gravimetric approaches require balancing the seedling in the water vessel at a specified point on the seedling so that plant tissue submerged in the water does not touch vessel walls (Burdette 1979). If the plant touches the container wall, the balance may fail to provide a steady reading, or the plant's frictional resistance may cause tissue volume to be underestimated. Any slight adjustment in holding the seedling may produce erroneous measures, compromising the accuracy and repeatability of the experiment.

In three experiments, a technique was tested for determining plant part volume and for quantifying new root production. This technique was designed to be simple and repeatable, using common laboratory equipment.

Materials and Methods

Gravimetric technique. The gravimetric technique uses several common laboratory devices (figure 1): a top-loading balance weighing to the nearest milligram; a 1,000-ml graduated cylinder filled with water; a clear plastic tube suspended in the graduated cylinder to support the seedling and prevent it from touching the walls of the graduated cylinder; and a ring stand and clamp to support the plastic tube.

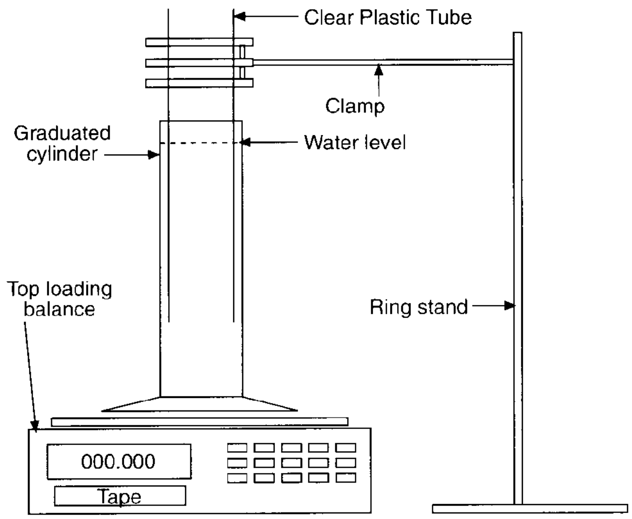

Figure 1A—*Schematic of gravimetric apparatus used for volume displacement analysis.*

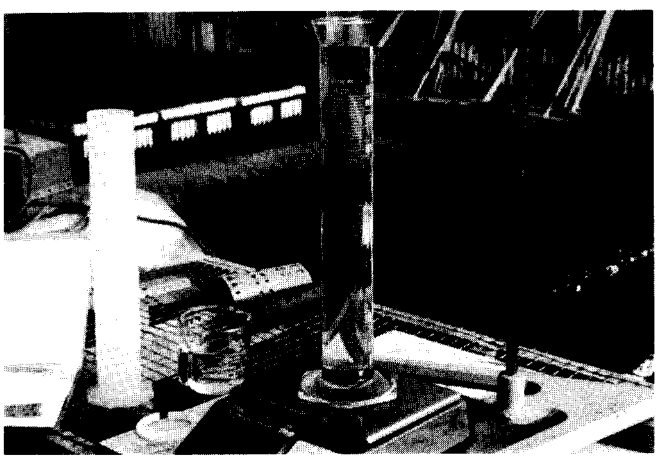

Figure 1B—*Close-up of graduated cylindar in gravimetric apparatus.*

Before volume measurement, seedlings were removed from their containers, and their root balls were rinsed free of medium under running water. The washed root systems were blotted dry. Then the balance weight was set to zero and the seedling tissue to be measured was placed into the water inside the plastic tube. To determine root system volume, the seedling was submerged until the surface of the water was 2 mm (0.08 in) above the uppermost lateral root (the cotyledon scar can also be used). This provided a reference point on the seedling for repeated measurement, thereby reducing experimental error. To determine shoot system volume, the seedlings were inverted and submerged until the surface of the water was 2 mm (0.08 in) above the base of the lowermost foliage (the cotyledon scar can also be used). Following immersion of the plant part to be measured, the new balance reading was recorded and used as an estimate of plant part volume.

Plant material. Container-grown eldarica pine *(Pinus eldarica* Medw.) and Arizona cypress *(Cupressus arizonica* Greene) were used in this study. Seedlings were grown for 20 weeks in Ray-Leach Super Cells® (164 cm^3; Ray-Leach Corporation, Oregon) containing a 2:1:1 (v / v / v) peat-perlite-vermiculite mixture. Seedlings were grown at the New Mexico State University Forestry Greenhouse located in Las Cruces, New Mexico. Ambient light was supplemented by 100-W incandescent bulbs to maintain a 16-hr photoperiod. Greenhouse temperatures ranged from 18 to 27 °C (64 to 81 °F) during the day to 16 to 23 °C (61 to 73 °F) at night. Seedlings were fertilized weekly with 15 ml of a modified Hoagland's nutrient solution (109 ppm nitrogen, 29 ppm phosphorus, and 17 ppm potassium).

Experiment 1. The first experiment examined the repeatability of the volume displacement technique. Root and shoot systems of the 20 pine seedlings over a range of sizes (based on shoot height) were measured 5 consecutive times using the volume displacement technique described above. Between measures, seedlings were blotted dry with paper towels. From this information, a mean value and coefficient of variation were calculated for the root and shoot tissues of each seedling.

Experiment 2. The second experiment examined the relationship of volume displaced to the tissue dry weight of seedlings measured. Root and shoot system volumes were determined for 48 eldarica pine and 19 Arizona cypress seedlings using the volume displacement technique described above. Seedling root and shoot systems were then separated and placed in a drying oven at 65°C (149 °F) for 48 hours. After drying, the seedling tissues were removed and weighed to the nearest milligram. Then the tissues were returned to the oven for an additional 24 hr and reweighed. No difference in dry weight measurements was found for the 48- and 72-hr treatments. From this information, regression analysis was used to examine the relation ship between volume estimation and tissue dry weight.

Experiment 3. In the third experiment, the volume displacement technique was evaluated for its utility in root growth potential (RGP) evaluation. Root system volumes of 30 eldarica pine seedlings were determined using the volume displacement technique described, above. Seedlings were then placed in an aeroponic rooting system (Rietveld and Timis 1987). After 14 days of incubation, seedling root systems were blotted dry and the volume measured again. New root volume was determined by subtracting the initial root volume from the root volume following RGP incubation. In addition, new roots greater than 0.1 cm (0.04 in) in length and greater than 0.5 cm (0.2 in) in length were counted for each seedling. From this information, regression analysis was used to determine the correlation between change in root volume and number of new roots greater than 0.1 cm (0.04 in) and 0.5 cm (0.2 in) in length.

Results

Experiment 1. This technique is repeatable, with coefficients of variation that are quite low for this type of measure, ranging from 0.22 to 2.00% for shoot tissue and 0.34 to 1.95% for root tissue (table 1). There was no apparent trend in variability based on tissue size.

Experiment 2. In experiment 2, strong relationships between volume displaced and tissue dry weight were found for shoot and root tissues of both species (figures 2 & 3). Linear correlation coefficients (r) for the relationships ranged from 0.91 for eldarica pine root tissue to 0.98 for Arizona cypress root and shoot tissues.

Table 1-*Size range of eldarica pine seedlings and coefficient of variation range for volume displacement technique*

Tissue	Size range (g)	CV range (%)
Shoot	3.90-7.60	0.22-2.00
Root	2.66-5.50	0.34-1.95

Experiment 3. In the third experiment, the increase in new root volume after the 14-day test period ranged from 5 to 50%. Most seedlings had at least a 10% increase in root volume, which was well above the coefficients of variation found in the first experiment (CV = 1.95%). The majority (mean = 75.8%) of the new roots produced during the RGP incubation were between 0.1 cm (0.04 in) and 0.4 cm (0.16 in) in length. The relationship between new root volume and number of new roots greater than 0.1 cm (0.04 in) had a

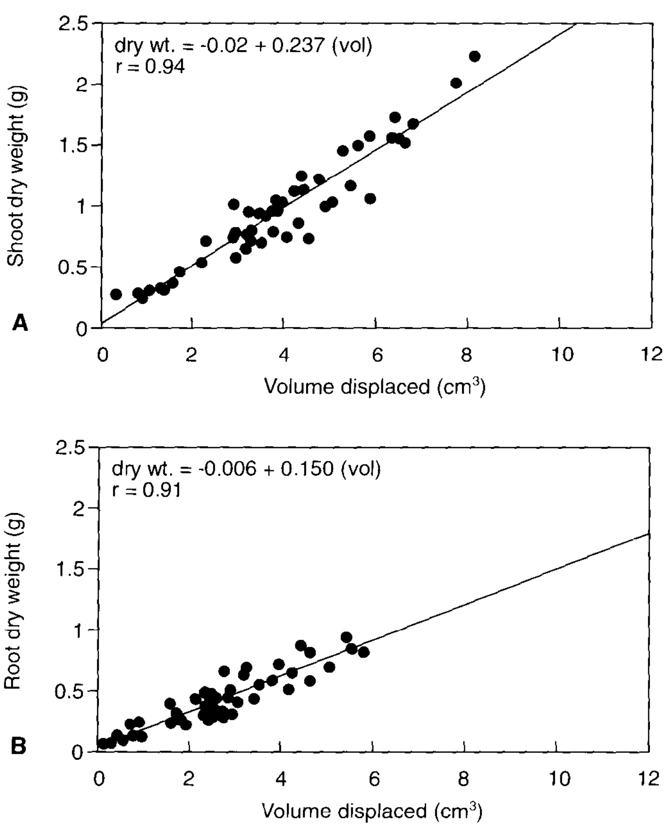

Figure 2—*Relationship between volume displaced and tissue dry weight for eldarica pine seedlings. Shoot tissue (**A**) and root tissue (**B**) are measured separately. Solid line represents fitted regression equation.*

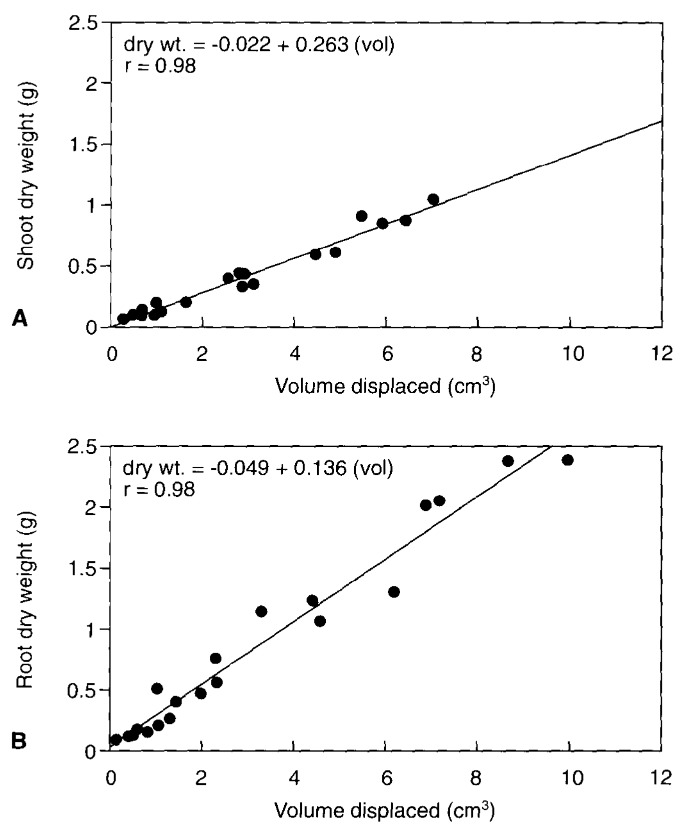

Figure 3—*Relationship between volume displaced and tissue dry weight for Arizona cypress seedlings. Shoot tissue (**A**) and root tissue (**B**) are measured separately. Solid line represents fitted regression equation.*

linear correlation coefficient of 0.80 (figure 4). The relationship between the number of new roots greater than 0.5 cm (0.2 in) and new root volume was not as strong, with a linear correlation coefficient of 0.53.

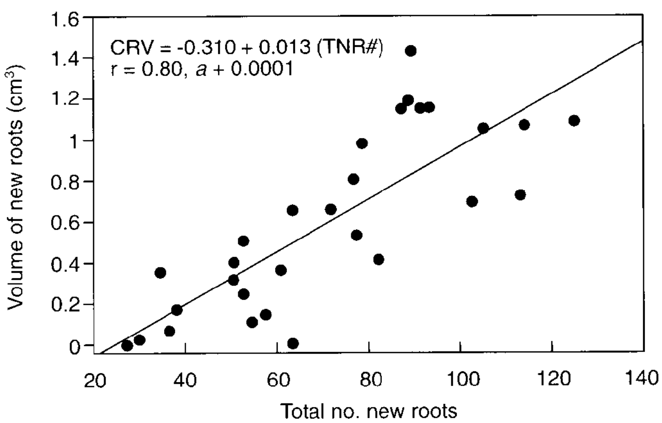

Figure 4—*Relationship between new root number and new root volume for eldarica pine seedlings. Solid line represents fitted regression equation.*

Discussion

This technique provides a nondestructive, repeatable approach to evaluating seedling morphology. Unlike previous gravimetric techniques (Novoselov 1960, Burdette 1979), this approach reduces emphasis on experimental mechanics (such as balancing the seedling and holding it steady) by using the plastic tube in the container (a "tube within a tube") to eliminate frictional resistance of plant tissue against container walls (see figure 1). Due to its nondestructive nature, this gravimetric technique allows for repeated measures through time on the test population, a decided advantage in RGP analysis. Moreover, it is simpler and faster than other techniques of assessing new root growth. Previous RGP studies have measured increases in root system using root area meters (Rietveld 1989), which can be expensive and difficult to calibrate. With stock that has fibrous root systems, root counts taken in most RGP studies can be very timeconsuming. It can take up to 5 minutes per seedling to count new roots in container-grown stock, and 10 minutes per seedling to measure new root length. By contrast, the gravimetric technique evaluated here can monitor new root production at a rate of 2 seedlings per minute, permitting larger sample sizes to be tested if needed.

In the third experiment, the poor correlation of volume displaced with the traditional measure of new root growth (roots longer than 0.5 cm, or 0.2 in) is related to the much greater frequency of new roots that were shorter in length. On average, roots ranging from 0.1 to 0.4 cm (0.04 to 0.16 in) in length constituted 75.8% of new roots per seedling.

Conclusions

This gravimetric technique has several applications in root growth analysis. First, it obviates the need for subsampling in studies of the developmental process of new root production and reduces the impact of the measurement process on seedlings. Second, it can be used to relate new root production to previous root volume (Burdette 1979). Finally, it can be used to obtain morphological measures potentially useful in RGP tests that employ covariates to reduce sampling error, as suggested by South and others (1989).

Address correspondence to John T. Harrington, New Mexico State University, Department of Agronomy and Horticulture, Mora Research Center, Box 359, Mora, NM 87732.

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Substrate and Temperature Tests for Germination of Atlantic White-Cedar Seeds

A. Bianchetti, R. C. Kellison, and K. O. Summerville

Seed technologist/visiting scholar, North Carolina State University; professor of forestry, North Carolina State University; and staff forester, Technical Development and Planning, North Carolina Division of Forest Resources, Raleigh, North Carolina

Experiments were conducted to evaluate temperatures and substrates for Atlantic white-cedar— Chamaecyparis thyoides *(L.) B.S.P.— seed germination. Seeds placed in petri dishes kept in germination chamber were tested at constant temperatures of 23 ºC (73 ºF) and 26 ºC (79 ºF) and at alternating temperatures of 20/30 ºC (68/86 ºF). Substrates tested were sand, vermiculite, and blue blotter. Best results were obtained with blue blotter under an alternating temperature regime*. Tree Planters' Notes 45(4):125-127; 1994.

Atlantic white-cedar— *Chamaecyparis thyoides* (L.) B.S.P— is an evergreen conifer usually found in small, dense stands in freshwater swamps, bogs, bays, and pocosins, on stream banks, and along lake shores. Although Atlantic white-cedar occurs primarily on the lower Coastal Plain, its range extends from Maine to Florida and west to Mississippi. It has been extensively logged, and its habitat has been so altered by human intervention that the species has lost much of its former abundance (Laderman 1989). Efforts to recolonize Atlantic white-cedar have only partly succeeded because of its poor seed germination and variable seedling development. To help overcome these obstacles, different temperatures and substrates were tested for germination of white-cedar seeds.

Materials and Methods

A bulked sample of Atlantic white-cedar seeds was furnished for the tests by the North Carolina Division of Forest Resources in Raleigh, North Carolina. Seeds in the sample were taken from 5 trees in each of 10 stands covering the range of Atlantic white-cedar in North Carolina. The seeds (including inert material) had been cold-stored for 15 months in a room at 3 to 5 ºC (37 to 41 ºF). The seedlot was manually cleaned, and light seeds were separated from heavy ones using a Dakota blower. Separation produced a 20% yield of heavy (viable) seed, a typical yield for the species. Light (nonviable) seeds were discarded, and heavy ones were pre-imbibed in water at room temperature (20 ºC, or 68 ºF) for 18 hours before treatment was begun.

Experiments were conducted with warm/ cold stratification to break seed dormancy, and without stratification (as a control). Tests with and without stratification were run separately, because the germination chamber was too small to accommodate all treatment combinations. Stratification was performed by placing petri dishes containing wet seeds in the germination chamber at 20 ºC (68 ºF) for 7 days, and then transferring them to another chamber at 5 ºC (41 ºF) for 7 days.

The treatments used for the trials consisted of combinations of three substrates (vermiculite, sand, and blue blotter) with two constant temperature regimes (23 ºC, or 73 ºF, and 26 ºC, or 79 ºF) and one alternating temperature regime (20/30 ºC, or 68/86 ºF). Under the alternating temperature regime, seeds were kept at 20 ºC (68 ºF) for 16 hours during the night, and at 30 ºC (86 ºF) for 8 hours during the day.

Four replications of 50 seeds per treatment were used for the germination trials. The experimental design was a completely randomized block containing 9 plots each for the stratified and nonstratified treatments, arranged in a 3-by-3 factorial (3 substrates x 3 temperature regimes), for a total of 18 treatments. Differences among means were determined by the Tukey test.

The germination period was determined to be 28 days, with counting done at 7-day intervals beginning on day 14, when the first germinants were observed. For a seed to be counted as a germinant, its cotyledon had to completely emerge above the substrate.

Results and Discussion

No stratification. Results from the trial without stratification (table 1) show that blue blotter was the best substrate at both 23 ºC (73 ºF) and 26 ºC (79 ºF), producing significantly ($P < 0.05$) higher germination than either sand or vermiculite. Under the alternating

Table 1 -*Germination of nonstratified Atlantic white-cedar seeds under three temperature regimes on three substrates*

	Percentage germination		
Temp.(°C)	Blue blotter	Vermiculite	Sand
23	11 Ba	8 Bbc	10 Bb
26	13 Ba	6 Bb	6 Cb
20/30	34 Aa	35 Aa	33 Aa

Note: Values followed by the same letter do not differ significantly (P < 0.05), according to the Tukey test. Uppercase letters (A, B, C) compare values by substrate (within columns); lowercase letters (a, b, c) compare values by temperature regime (within rows).

temperature regime, there was no significant ($P < 0.05$) difference in germination rates among substrates, but alternating temperatures produced much higher germination rates than either of the constant temperature regimes. Similar results were found by Okoro (1976) for *Terminalia ivorensis* seeds, which are similar in size to white-cedar seeds.

Stratification. Results from the trial with stratification (table 2) show no significant ($P < 0.05$) difference in germination rates among substrates under any given temperature regime, and no significant ($P < 0.05$) difference in germination rates under the two constant temperature regimes, regardless of substrate. But for all three substrates, alternating temperatures produced much higher germination rates than the constant temperature regimes.

In both experiments, an alternating temperature regime and (to some degree) a higher constant temperature increased seed germination on the blue blotter. Moreover, warm/ cold stratification produced about 10% more germination (averaged across all substrates and temperatures) than did nonstratification. Similar results were found by Bianchetti and others (1993) when white-cedar seeds were pretreated in water at 40, 60, 80, and 100 ºC (104, 140, 176, and 212 ºF) for 18 hours and then prechilled at 5 ºC (41 ºF) for 14 days, or warm-stratified at 20 ºC (68 ºF) for 7 days and then prechilled for an additional 7 days. These results suggest that white-cedar seeds respond promptly to temperature changes. Although all three substrates produced about the same rate of germination under the alternating temperature regime, blue blotter is recommended because it is inexpensive, requires no covering layer of substrate over the seeds, and contrasts with the dark brown color of the seeds, allowing them to be easily counted and spaced. Sand and vermiculite are more difficult to handle and usually require a thin covering layer of substrate over the seeds. Sand is preferable to vermiculite because it contrasts with the seeds in color, causing fewer mistakes in, assessing germination and spacing seeds in the germinator box.

Table 2 -*Germination of stratified Atlantic white-cedar seeds under three temperature regimes on three substrates*

	Percentage germination		
Temp. (°C)	Blue blotter	Vermiculite	Sand
23	16 Ba	16 Ba	16 Ba
26	19 Ba	20 Ba	19 Ba
20/30	41 Aa	38 Aa	41 Aa

Note: Values followed by the same letter do not differ significantly (P < 0.05) according to the Tukey test. Uppercase letters (A, B, C) compare values by substrate (within columns); lowercase letters (a, b, c) compare values by temperature regime (within rows).

Conclusions

This study found that:

- Poor germination of Atlantic white-cedar seeds is linked to the high proportion of empty seeds and inert material found in seedlots. The 80:20 ratio of nonviable to viable seeds found here is typical of the species.
- Stratification improves germination, regardless of temperature and substrate, but improvement is only marginal.
- Different substrates (sand, vermiculite, and blue blotter) produce no significant differences in germination, but blue blotter is recommended because it is less expensive and easier to use.
- For both stratified and nonstratified seeds, alternating temperatures of 20 / 30 ºC (68 / 86 ºF) produce higher germination rates than constant temperatures of 23 ºC (73 ºF) and 26 ºC (79 ºF). A higher constant temperature produces marginally better results than a lower constant temperature.

Further studies are needed to determine how to accelerate and increase seed germination using alternating temperature regimes.

Address correspondence to Robert Kellison, North Carolina State University, Hardwood Research Cooperative, Box 8002, Raleigh, NC 27695.

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Importance of Release for Naturally Seeded and Planted Container Loblolly Pines on a Cutover Site

Michael D. Cain and James P. Barnett

Silviculturalist and project leader, USDA Forest Service, Southern Research Station
Monticello, Arkansas, and Pineville, Louisiana

Genetically improved container loblolly pine (Pinus taeda *L.) seedlings were compared to naturally established loblolly seedlings on a cutover pine site. Measurement pines on 6 of 12 plots were released from woody and herbaceous competition in a 61-cm (2 ft) radius around each tree stem. Woody competition was controlled by hand cutting for 5 consecutive years, and herbaceous competition was controlled with herbicides for 4 consecutive years. Competition control increased 6-year survival by 26% for both natural and planted pines. Six years after field establishment, planted pines had a 73% higher volume index than naturally established pines. Large volume gains resulted from release for both regeneration techniques (544% for planted pines and 663% for naturally established pines).* Tree Planters' Notes 45(4):128-136; 1994.

In the management of southern pines, release treatments can alter the competitive balance on regenerated sites and thereby improve the survival and growth of juvenile pines (Cain and Mann 1980, Clason 1984, Haywood 1986). When intensive treatments were applied to control woody and herbaceous vegetation, substantial 5-year growth gains were observed for planted loblolly pines *(Pinus taeda* L.*)* (Miller and others 1991) and naturally seeded loblolly pines (Cain 1991b). However, results from investigations on plantations are often not directly comparable to those on natural stands because of variations in site, competing species, and treatments.

Many forest landowners may attempt to reduce their establishment expenditures by outplanting improved seedlings where site conditions are less than optimal. These landowners need to know how improved pine seedlings compare to naturally regenerated pine in terms of potential growth following minimal (that is, low-cost) site preparation.

Although the benefits of release are well documented, there is little information on how naturally seeded and planted loblolly pines respond to release treatments applied uniformly within the same research study. Our objectives were (1) to compare loblolly pines established by natural seedfall to outplanted container loblolly pines from a genetically improved seed source in terms of survival and juvenile growth and (2) to determine if control of woody and herbaceous competition produces different responses in naturally established pines than in planted, genetically improved pines. Container seedlings were chosen because they provide an efficient use of genetically improved seed, are quickly produced, and have an extended planting season (Barnett and Brissette 1986).

Methods

Study area. The study was conducted on a 2-ha (5-acre) clearcut on the Crossett Experimental Forest in southern Arkansas (figure 1). The soil was Bude silt loam (Glossaquic Fragiudalf), with a site index of 27m at 50 years for loblolly pine.

Between 1934 and 1969, pines in the study area had been intensively managed using single-tree selection: better pines were exempted from harvest until reach-

Figure 1—*Portion of the 2-ha (5-acre) study area in southern Arkansas at time of study initiation (early spring 1987, 2 years after clearcutting and 1 year after spot treatment with hexazinone herbicide).*

ing a diameter at breast height (dbh) of 46 to 61 cm (18 to 24 in). In the mid-1980's, the site contained an overstocked, uneven-aged stand of loblolly and shortleaf pines *(Pinus echinata* Mill.*)* infested with southern pine beetles *(Dendroctonus frontalis* Zimm.). In summer 1985, trees were clearcut on about 2 ha (5 acres) to salvage approximately 132 m^3/ha (11,000 fbm /acre, Doyle scale) of pine sawlogs killed by bark beetles.

In April 1986, 1 year after clearcutting, the entire area was spot-treated with hexazinone (Velpar® L) at the rate of 3.4 kg ai / ha (3 lb ai / acre) using herbicide spotguns on a 0.9- by 0.9m (3- by 3-ft) grid to control nonpine vegetation. This treatment controlled the larger hardwoods but was less effective on hardwood seedlings, shrubs, and herbaceous vegetation. In summer 1987, a few surviving hardwoods taller than 1.8 m (6 ft) were basally injected with a 50% solution of glyphosate.

Study design and treatment. A completely randomized statistical design was used, with three replications of four treatments: natural pine seedlings (N), natural pine seedlings plus release (N / R), planted container pine seedlings (P), and planted container pine seedlings plus release (P/R). "Release" refers here to freeing a tree from immediate competition by eliminating vegetation that overtopped or closely surrounded the tree in a 61-cm (2-ft) radius around its stem. For the purpose of this investigation, "seedlings" had a dbh of less than 1.5 cm (0.6 in), and "saplings" had a dbh greater than or equal to 1.5 cm (0.6 in) but less than 9.1 cm (3.6 in).

Each of 12 plots measured 28.4 by 28.4 m (93.3 by 93.3 ft), with 19.2- by 19.2-m (63- by 63-ft) interior subplots. Individual plots accommodated 121 planting spots for crop pines on a 2.7- by 2.7-in (9- by 9-ft) spacing. The 49 crop pines on interior subplots were used as measurement trees. The two regeneration techniques-natural seeding and planting seedlingswere randomly assigned to each of six plots.

Loblolly pine seeds for the container stock were obtained from the Kisatchie National Forest Seed Orchard in central Louisiana, but the original clone selections were from a northern Louisiana source. The open-pollinated seeds were from a bulk orchard lot that had been collected in 1984 before the seed orchard was rogued. The expected genetic gain was about 5% over nursery-run stock.

In mid-September 1986, seeds for the planting stock were sown in Ray-Leach Stubby Cells® filled with a 1:1 peat-vermiculite medium. Greenhouse cultural treatments followed guidelines described by Barnett and Brissette (1986). Because the seedlings were grown during winter, development was slow and the stock was about 26 weeks old when outplanted in early April 1987. At outplanting, pine shoot length averaged 11.6 cm (0.38 ft) and groundline diameter (gld) averaged 2.5 mm (0.1 in). The seedlings were considered small because the recommended shoot length of container loblolly pine seedlings is 15 to 20 cm (0.5 to 0.7 ft) at outplanting (Barnett and Brissette 1986). Although smaller than recommended, container seedlings had a distinct height advantage over natural pine seedlings that had just begun to germinate from seed (figure 2).

Natural pines dropped seeds onto the study area from autumn 1986 through winter 1987. An estimate of natural pine seed production was obtained from 0.2-m^2 (2.2-ft^2) seed collection traps. One trap was placed 0.6 m (2 ft) above ground at the center of each 0.08-ha (0.2-acre) plot. Seed counts were made weekly from October 1986 through February 1987. The seedcrop

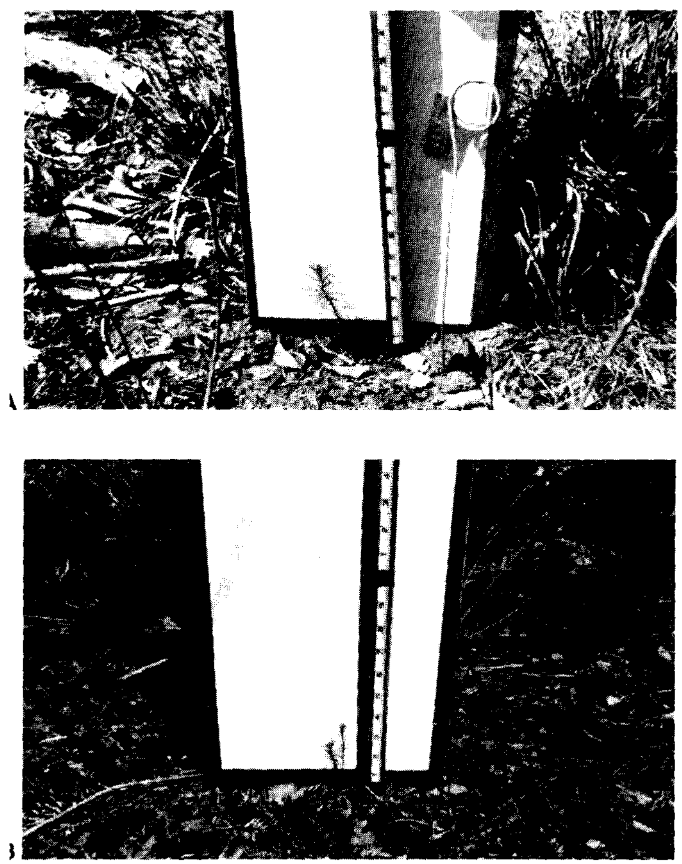


Figure 2—*Container loblolly pine seedling (**A**) shortly after outplanting in April 1987, and natural loblolly pine seedling (**B**) from the 1986-87 seedcrop, photographed in April 1987.*

averaged over 740,000 seeds / ha (300,000 seeds / acre), with 75% judged potentially viable when tested with the seed cutting test described by Bonner (1974). The 1985-86 seedcrop from the previous winter had been judged a failure, with only 7,400 potentially viable seeds/ha (3,000 seeds/acre) (Cain 1991a). An average seed year for loblolly pine is expected to produce from 74,000 to 198,000 viable seeds/ ha (30,000 to 80,000 seeds/ acre), so the 1986-87 seedcrop appeared to be outstanding.

In early summer 1987, 49 natural seedlings were selected as measurement trees and tagged for identification on each of the 6 interior plots where the growth of natural pine regeneration was monitored. Their selection was based on seedling quality and spacing. The tallest first-year seedlings were usually chosen if their terminal buds were intact, although other quality criteria were used as well-for example, the presence of dark green needles and absence of insects, disease, and mechanical damage. A total of 294 natural pine seedlings and 294 planted pine seedlings were tagged for measurement. All other natural pine seedlings were left undisturbed.

Beginning in the 1987 growing season, measurement pines were released from woody and herbaceous competition on three planted plots and three naturally seeded plots (table 1). With machetes, woody vegetation was cut below pine height in a 61-cm (2-ft) radius around preselected pines. Then, within the same 61-cm (2-ft) radius, sulfometuron methyl was applied at 0.26 kg ai / ha (3.75 oz ai / acre) and glyphosate was applied at 0.76 kg ai / ha (0.68 lb ai /acre) to control herbaceous vegetation (figure 3). The herbicides were dispersed as water solutions at the rate of 103 L/ha (11 gal/ acre) using backpack sprayers, and pines were shielded at time of treatment. Cutting was always done before herbicide was applied. Sulfometuron was the principal herbicide used because of pine's tolerance to it; glyphosate was included only in the 3rd and 4th growing seasons to control broomsedge *(Andropogon virginicus* L.), which is resistant to sulfometuron. Some volunteer natural pine seedlings became established within the 61-cm (2-ft) treatment radius after the first year of release but were not intentionally eliminated until the dormant season of the 4th year because they were considered no great impediment to the growth of crop pines.

Measurements and data analysis. After the first year of field establishment, measurement tree heights were taken to the nearest 3 cm (0.1 ft), and gld was measured to the nearest 1 mm (0.04 in). Total heights and gld's were remeasured, using the same degree of accuracy, on all surviving measurement pines at the end of the 3rd, 4th, 5th, and 6th growing seasons. As an estimate of tree volume, total height x gld^2- was calculated and reported as volume index. At each inventory, dbh measurements were taken to the nearest 1 mm (0.04 in) on all crop trees taller than

Table 1 -*Pine release treatments applied during first 5 years after field establishment*

Time of release	Type of release: Manual cutting	Sulfometuron	Glyphosate
1987			
Spring	o	"	"
Summer	+	+	o
1988			
Spring	+	+	o
Summer	+	+	o
1989			
Spring	+	+	o
Summer	+	+	+
1990			
Spring	+	o	+
Summer	+	"	"
1991			
Spring	o	"	"
Summer	+	"	"

Note: += treatment applied;o = no treatment. Spring treatments were applied in April, summer treatments in June or July.

Figure 3—*Herbicide being applied around 3-year-old natural loblolly pine seedlings to control herbaceous vegetation.*

1.37 m (4.5 ft). After 6 growing seasons, height-to-live-crown was measured to the nearest 3 cm (0.1 ft) on all surviving crop trees, and crown widths were measured to the nearest 3 cm (0.1 ft) at the widest axis and perpendicular to that axis on a random sample of 15 pines per plot.

Measurement pines were judged as free-to-grow if the terminal leader was not overtopped by the foliage of competing vegetation. If pines were overtopped, then the competing species was recorded. Estimates of natural pine and woody rootstock densities and quadrat stocking were obtained from an inventory of 9 temporary 4-m^2 (1-milacre) circular quadrats (10% sample) that were systematically located on each interior plot. The most recent inventory for assessing population dynamics of natural pine and hardwood rootstocks was conducted 6 years after site preparation with hexazinone.

Analysis of variance for a completely randomized design was used to evaluate treatment effects on pine survival and overtopped status. Percentage values for survival and overtopped status were compared among treatments following arcsine transformation. Sizes of measurement pines were first subjected to analysis of covariance, with first-year sizes as covariates. Because covariates proved nonsignificant, all variables were reanalyzed by analysis of variance. Statistically significant treatment differences ($P < 0.05$) were tested by orthogonal contrasts as follows: N vs. N/R; P vs. P/R; and N+N/R vs. P+P/R

Cost of release was determined from the average number of worker-hours required to manually cut the woody competition and to chemically treat the herbaceous vegetation in a 61-cm (2-ft) radius around 1,500 pines/ha (607 pines/acre). Whenever treatments were applied, records were maintained of the time required to cut the hardwoods and spray the herbicides on a plot-by-plot basis. The cost of unskilled labor was based on a minimum wage of $4.25 / hr. Herbicide costs were based on 1992 retail prices: $351 / kg ($159/lb) for sulfometuron and $29/L ($111/gal) for glyphosate. Release treatments were applied by USDA Forest Service personnel to assure quality control.

Results

Pine response to treatments. After 6 growing seasons, release treatments had improved survival of crop pines by 26% on both naturally regenerated plots ($P = 0.0079$) and planted plots ($P = 0.0175$) (table 2). There was no difference in pine survival between the two regeneration techniques ($P = 0.4930$).

Table 2 -*Survival and overtopped status of measurement pines 6 years after field establishment*

Treatment comparisons	% survival	(PR > F)[a]	Overtopped status (%)	(PR > F)[a]
Natural	71		64.5	
		0.0079		0.0001
Natural/Release	97		2.2	
Planted	69		59.5	
		0.0175		0.0003
Planted/Release	95		7.3	
N + N/R	84		33.4	
		0.4930		1.0000
P + P/R	82		33.4	
Mean square error	0.0374		0.0140	

[a] The probability of obtaining a larger F-ratio under the null hypothesis. Orthogonal contrasts are natural vs. natural/release, planted vs. planted/release, and N + N/R vs. P + P/R.

Of nonreleased pines still alive after 6 years, 60% or more were overtopped by competing vegetation, regardless of regeneration technique (table 2). One year after the final release treatment, 98% of survivors on released natural plots and 93% of survivors on released planted plots were judged free-to-grow (table 2).

As a result of competition control, mean increases ($P < 0.01$) in height over 6 years were 2.07 m (6.79 ft) on natural pine plots and 2.40 m (7.87 ft) on planted pine plots (table 3). After 6 growing seasons, planted pines were 13% taller ($P = 0.0065$) than naturally regenerated pines.

Release resulted in average gains for natural pines of 157% in dbh and 183% in gld ($P < 0.01$), and for planted pines of 125% in dbh and 159% in gld ($P < 0.01$) (table 3). Six years after field establishment, planted pines were 28% larger ($P < 0.01$) in gld and 32% larger ($P < 0.01$) in dbh than natural pines.

After 6 growing seasons, mean differences in volume index per tree between release treatments averaged 0.03 m^3 (1.00 ft^3) ($P < 0.01$) on natural pine plots and 0.05 m^3 (1.65 ft^3) ($P < 0.01$) on planted pine plots (table 3). Planted pines had 73% more ($P < 0.01$) volume than naturally regenerated pines.

Within each regeneration technique, crown widths of released pines averaged more than twice ($P < 0.01$) the width of nonreleased pines, and crown widths on planted pines were 23% larger ($P < 0.01$) than on

Table 3 -*Mean size of surviving measurement pines 6 years after field establishment*

Treatment comparisons	Total height (m)	Gld (mm)	Dbh (mm)	Volume index (m^3)	Crown width (m)	Live-crown ratio (%)
Mean size						
Natural	2.36	27.9	19.8	0.0043	0.68	51
Natural/Release	4.43	79.0	50.8	0.0328	1.62	70
Plante d	2.64	37.8	28.4	0.0086	0.87	53
Planted/Release	5.04	98.0	64.0	0.0554	1.95	65
N + N/R	3.40	53.3	35.3	0.0185	1.15	61
P + P/R	3.84	68.1	46.5	0.0320	1.41	59
Mean square error	4.52E-02	28.6451	13.8817	2.70E-05	9.64E-03	7.00E-04
Probabilities of a greater F-value						
Natural vs. Natural/Release	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001
Planted vs. Planted/Release	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
N+N/R vs. P + P/R	0.0065	0.0015	0.0010	0.0021	0.0019	0.0957

naturally regenerated pines (table 3). With release, live-crown ratios were 12% and 19% larger (P < 0.01) for planted and natural pines, respectively. However, there was no difference (P > 0.05) in live-crown ratio between the two regeneration techniques (table 3).

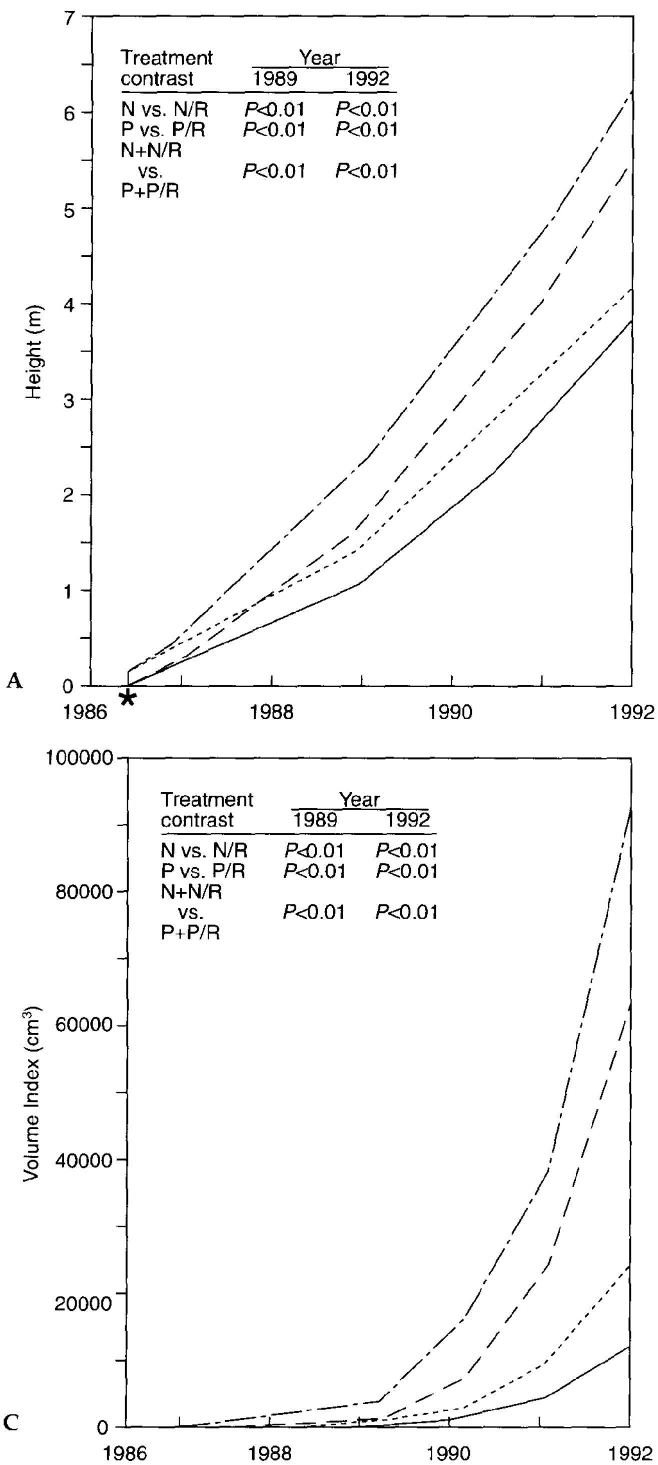
Six years after the hexazinone treatment, density of natural pine regeneration averaged 16,360 stems/ ha (6,621/acre) for seedlings and 1,601 stems/ ha (648/acre) for saplings. Quadrat stocking for these natural pines ranged from 33% for saplings to 88%> for seedlings.

The tallest 247 pines per hectare. To better assess treatment efficacy, it is often desirable to look at how the tallest 247 trees/ha (100/acre) respond. For these pines, periodic growth in height, gld, and volume index was better (P < 0.01) with release than without, and differences increased with time (figure 4). Within 2 years of field establishment, growth of dominant released natural pines surpassed that of dominant planted pines where there was no release (figure 4). However, as a group, planted pines outperformed naturally regenerated pines by the equivalent of a half year's growth or more at age 5 to 6 years.

Diameter distributions for the tallest trees at age 6 are illustrated in figure 5. Released pines of both regeneration types reached pulpwood size (9.1 cm, or 3.6 in, in dbh) by age 6. Nonreleased pines, however, did not reach pulpwood size, regardless of regeneration technique.

Competing vegetation. Species that overtopped surviving pines on nonreleased plots 6 years after establishment included eight trees, two shrubs, and three vines (table 4). Japanese honeysuckle *(Lonicera japonica* Thunb.) was the most troublesome competitor, overtopping 49% of surviving pines on natural plots and 45% on planted plots. Trees accounted for less than 11% of individual overtopping competitors, and they overtopped fewer pines overall than did Japanese honeysuckle. The most prolific shrub was American beautyberry *(Callicarpa americana* L.). The original treatment of the site 7 years earlier with hexazinone had failed to adequately control this shrub due to its resistance to this herbicide (McLemore 1983).

Because of minimal site preparation, the area was overgrown with nonpine vegetation. Seven years after clearcutting, and 6 years after hexazinone was applied, woody nonpine species had an average density of 10,845 rootstocks / ha (4,389 / acre) for seedling-size stems and 2,014 stems / ha (815 stems / acre) for saplings. Quadrat stocking averaged 96 and 44%, respectively, for seedling-size and sapling-size hardwood rootstocks. These findings are consistent with results from a study by Cain and Yaussy (1984), which indicated that hardwoods cannot be eradicated from



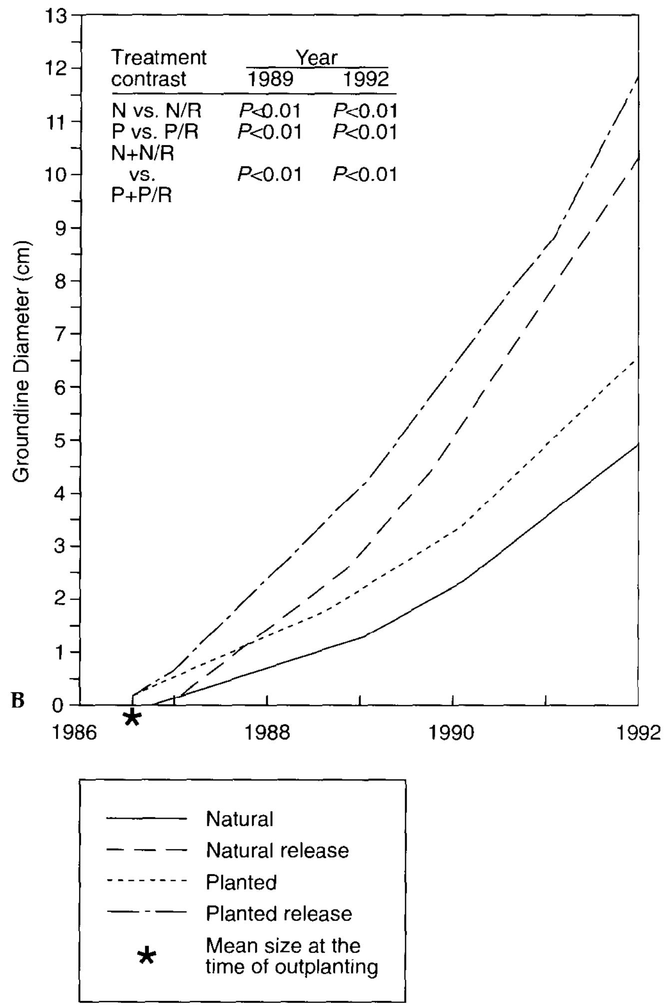


Figure 4—*Periodic growth trends for the tallest 247 pines/ha (100 pines/acre) by regeneration technique, with and without release: (**A**) height, (**B**) groundline diameter, and (**C**) volume index.*

such sites, even with intensive mechanical and chemical treatments.

Cost of regeneration and release. A well-stocked stand of mature, seed-bearing loblolly pines surrounded this 2-ha (5-acre) clearcut and produced a better-than-average seedcrop during the winter preceding the study. Consequently, pine regenerated naturally at no cost to the landowner.

Loblolly pine container stock can be purchased for operational planting at a price of $130 per thousand (McRae 1994), or about $195/ha ($78/acre) for a density of 1,500 trees/ha (607/acre). The same price prevailed in 1987, when container pines were outplanted for this study. In Arkansas, bareroot loblolly pine seedlings from an improved seed source can be obtained through the Arkansas State Forestry Commission at a cost of $30 per thousand, or about $45/ha ($18/acre) for a density of 1,500 trees/ha (607 trees / acre).

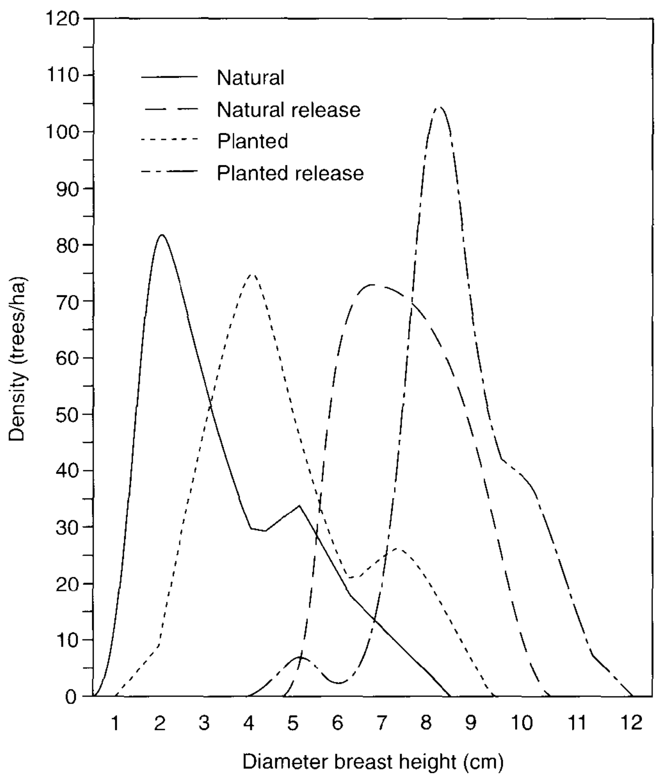


Figure 5—*Diameter distributions for the tallest 247 pines/ha (100 pines/acre) at age 6, by regeneration technique, with and without release.*

Table 4 -Relative proportion of competing species that overtopped surviving measurement pines on nonreleased plots at age 6.

	Pine overtopped (%)	
Overtopping species	Natural	Planted
Trees		
Acer rubrum L.	6.3	7.6
Cornus florida L.	3.0	5.0
Ilex opaca Ait.	—	10.2
Liquidambar styraciflua L.	—	5.4
Prunus serotina Ehrh.	1.6	3.0
Quercus nigra L./*Q. phellos* L.	1.4	4.8
Sassafras albidum (Nutt.) Nees	5.1	1.7
Shrubs		
Callicarpa americana L.	31.9	14.6
Vaccinium L. spp.	1.6	----
Vines		
Gelsemium sempervirens (L.) Ait. f.	—	1.5
Lonicera japonica Thunb.	49.1	44.7
Rubus L. spp.	----	1.5
Total	100.0	100.0

The cost of hand-planting bareroot seedlings on cutover land on the Coastal Plain following less-than-intensive site preparation in 1992 was reportedly $87/ ha ($35 / acre) for a density of 1,500 trees / ha (607 trees / acre) (Belli and others 1993). Because container pine seedlings are easy to hand-plant with conventional bareroot planting tools (Barnett and Brissette 1986), planting costs for container pines should be similar to bareroot planting costs. With seedling costs ranging from $45/ha ($18/acre) for bareroot stock to $195/ha ($78/acre) for container stock, and with planting costs at $87/ha ($35/acre), it costs from $132/ha ($53/acre) to $282/ha ($113/acre) more to plant pine seedlings than to rely on natural pine regeneration.

The costs of release treatments (table 1) were as follows: wages for manual cutting were $0.05 /tree; wages for herbicide application were $0.03 / tree; the cost of sulfometuron was $0.08 /tree; and the cost of glyphosate was $0.03 /tree. Costs do not include the purchase price of handtools or backpack sprayers.

Discussion

Planted container stock outperformed pines of natural origin in this investigation, and pines that were released from woody and herbaceous competition in a 61-cm (2-ft) radius around each stem exhibited more vigor and better growth than those that were not released, regardless of regeneration technique. According to Baker and Langdon (1990), diameter growth of individual loblolly pines generally increases as crown surface area and crown ratio increase, with optimal diameter growth in trees with at least 40% live-crown ratio. A mortality rate of 30% for crop pines that were not released during the first 6 years after field establishment is attributed mainly to dense shading from overtopping vegetation, primarily American beautyberry and Japanese honeysuckle.

Adequate density and quadrat stocking of pine regeneration was achieved by natural seeding across a 2-ha (5-acre) clearcut without the benefit of intensive site preparation. In the absence of release, less than half of the dominant natural pines were judged free-to-grow after 6 years. But pines were so dense that there seemed to be no immediate need for release. One longterm research study conducted less than 0.8 km (0.5 mile) from the site of this study showed that small clearcuts of about 2 ha (5 acres) will naturally regenerate with seed from bordering loblolly and shortleaf pine seed trees; despite low-intensity site preparation, and even without followup control of competition, well-stocked stands of sawlog-size pines will develop on these sites (Baker and Murphy 1982). Still, the present study shows that release treatments can substantially improve pine yields through age 6.

Release treatments in a 61-cm (2-ft) radius around 1,500 pines/ha (607 pines/ acre) had little impact on density and quadrat stocking of woody vegetation because the treatments were restricted to 18% of the plot area. Spot treatments for pine release are often more advantageous than band or total control treatments because more vegetation remains to stabilize soil, improve landscape appearance, and provide food and cover for wildlife (Yeiser and Barnett 1991). In an evaluation of spot size for controlling herbaceous vegetation to improve the growth and survival of recently planted loblolly pines, Dougherty and Lowery (1991) noted that from an environmental standpoint it was important to treat the smallest area needed to provide the desired response. However, there are disadvantages to spot treatments compared to broadcast treatments: costs are often higher because of intensive labor requirements, and workers usually are exposed to increased amounts of herbicides.

Natural regeneration of loblolly pines is still a viable alternative to planting and is especially desirable for landowners who prefer low-cost establishment. We do not suggest that the costs associated with 5 years of intensive competition control on small plots are operationally feasible. However, chemical release may be operationally achieved by ground application with backpack sprayers. According to Belli and others (1993), the cost of such treatment on the Coastal Plain in 1992 was $119/ha ($48/acre).

Further research is needed to determine if operational spot release will improve the growth of natural and planted loblolly pines. In an evaluation of the long-term effect of weed treatments on stand growth, Busby (1992) reported that single spot treatments of sulfometuron in a 53-cm (1.75ft) radius around loblolly pines provided economically efficient control of herbaceous weeds (regardless of rate of application) for all combinations of site and planting density. In this study, costs for spot treating 1,730 trees/ha (700 trees/ acre) with 0.28 kg (4 oz) ai of sulfometuron were about $60/ha ($24/acre) on cutover sites.

Data from the present investigation suggest that container loblolly pines from a genetically improved seed source that are outplanted on areas with minimal site preparation will equal or exceed the growth of naturally established pines. To maximize survival and growth potential of genetically improved planting stock on good sites, some degree of herbaceous and woody competition control seems justified during the first few years after pine establishment. When using loblolly pine container stock on an operational basis, outplanted seedlings should be larger than those used in this study (Barnett 1991). The general rule for southern pine planting stock is that the higher the morphological grade or the larger the seedling, the better survival and growth will be (Wakeley 1954).

Address correspondence to Michael D. Cain, USDA Forest Service, Southern Research Station, Monticello, AR 71656.

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Treatments for Enhancing Early Survival and Growth of Northern Red Oak Seedlings

David M. Hix, Charles A. McNeel, and Edwin C. Townsend

Assistant professor, School of Natural Resources, The Ohio State University, Columbus, OH; former research assistant, Division of Forestry, College of Agriculture and Forestry, West Virginia University, Morgantown, WV; and associate professor, Statistics Department, College of Agriculture and Forestry, West Virginia University, Morgantown, WV

Early survival and height growth of underplanted 2+0 northern red oak (Quereus rubra L.) *nursery stock and of naturally established seedlings in northern West Virginia were evaluated one field growing season after treatments in a replicated multi-split-plot experiment. Tubex tree shelters 1.5 m (5 ft) tall promoted planted northern red oak height growth and general vigor (form and number of leaves) but did not affect survival. Understory treatment (application of herbicide to stumps) reduced the average height of woody vegetation competing with natural oak seedlings, and survival rates of major competing species (black cherry and red maple) were less. Results suggest that height growth of northern red oak seedlings may be enhanced by using tree shelters and by understory treatment on excellent sites.* Tree Planters' Notes 45(4):137-141; 1994.

Mixed-oak forests on high-quality sites across the eastern United States often do not regenerate to oaks following conventional timber harvesting methods (Trimble 1973, Hilt 1985, Crow 1988). Shade-tolerant species of lesser value are replacing oaks on better sites in many areas (Johnson 1976, Hix and Lorimer 1991). A major hindrance has been the lack of well-established advance regeneration of desirable species such as northern red oak *(Quercus rubra* L.). Understories present in these forests today are developing under much different disturbance regimes than in the past (Nowacki and others 1990, Abrams 1992): fire suppression has replaced frequent burning, for example.

The shelterwood method has been recommended for regenerating mature oak stands that lack adequate advance oak regeneration (Sander and others 1983, Hannah 1988). Loftis (1990) suggested using shelterwood cuts and controlling undesirable understory stems to encourage the development of desirable reproduction. Other researchers have concluded that herbicide control of midstory and understory competition is often needed (Horsley 1982, Janzen and Hodges 1987). Underplanting has been used to supplement natural oak regeneration in areas where oak is scarce (Tworkoski and others 1986). Pubanz and others (1989) found that planted oak seedlings in Wisconsin had better survival, growth, and vigor after overstory density was reduced and the understory controlled. Tree shelters have been found to increase early growth rates of planted oak seedlings (Potter 1988, Minter and others 1992, Smith 1993). Tree shelters also protect trees from many types of animal damage, including deer browsing (Kittredge and others 1992).

Thus, prescriptions that combine the shelterwood method with intensive understory management have been proposed for regenerating oaks naturally (Lorimer 1989), as well as for planting northern red oak (Johnson and others 1986). But few tests of these prescriptions have been done in mixed-oak forests of the central Appalachians. This study was designed to evaluate the usefulness of various combinations of underplanting, shelterwood cutting, tree shelter use, and understory treatment with herbicide in regenerating oak forests on high-quality sites.

Study Area and Methods

The University Forest in northern West Virginia near Morgantown was chosen as the site for this study. In May 1990, a multi-split-plot experiment was initiated with the following levels: site quality, shelterwood cutting, understory herbicide treatment, and tree shelter use on planted northern red oak seedlings. Two types of sites were selected for study: excellent sites, with northeast aspects and an average site index for northern red oak of 27 m at 50 years; and good sites, with northwest aspects and an average site index for northern red oak of 23 m at 50 yr. Three pairs of 0.4-ha (1-acre) plots were located on excellent sites, and two pairs on good sites. Plots within pairs were separated from each other by 20-m (66-ft) buffer strips. On all sites, overstories were dominated by yellowpoplar *(Liriodendron tulipifera L.),* white oak *(Quercus alba* L.), and northern red oak. Soils on the plots were stony sandy loams, and slopes ranged from 10 to 40%. Plots were all located in midslope positions at an average elevation of 675 m (2,215 ft).

During late winter and very early spring 1991, a shelterwood establishment cut was done on one randomly selected plot in each plot pair. These cuts removed overtopped and some intermediate crown-class trees, reducing crown cover from almost 100% to an average of 85%, as measured using a spherical densiometer (Lemmon 1956). Immediately after shelterwood cutting, an understory herbicide treatment was applied to half of each plot, again selected at random, forming 0.2-ha (0.5-ac) subplots. Understory treatment consisted of cutting near the ground all non-oak stems with a diameter at breast height of less than 1.6 cm (0.6 in), and then immediately applying herbicide (either trichlopyr or a mixture of picloram and 2,4-D) to the stumps to control resprouting.

In each plot, four 0.04-ha (0.1-acre) sub-subplots were established around the plot center, sharing the stake as a common corner. Within each subplot, one of the two sub-subplots was randomly chosen for natural regeneration, and 2+0 northern red oak nursery stock was planted on the other. Seedlings were obtained from the state nursery near Parkersburg, West Virginia, and planted during spring 1991. Before planting, seedlings were pruned at 20 cm (8 in) both above and below the root collar. Approximately 25 seedlings were planted per sub-subplot using 3- by 3-m (9.8- by 9.8-ft) spacing. A total of 500 seedlings were planted, about half of them protected by cylindrical Tubex® tree shelters 1.5 m (5 ft) tall. The shelters were pushed down into the soil around the seedlings and fastened to treated wooden stakes.

During summer 1990, initial plot measurements were taken before treatments were applied. On each natural regeneration sub-subplot, all understory tree species were inventoried by species and height class. Then subsamples of the following species were tagged: northern red oak, white oak, black cherry (*Prunus serotina* Ehrh.), and red maple (*Acer rubrum* L.). The location of each tagged seedling was mapped. For each subsampled seedling, total height was measured. To assess the general vigor of oaks, numbers of leaves were counted. Oak seedlings were then assigned to one of the following growth form classes: flat-topped, intermediate, and with distinct central leaders. At the end of the first field growing season (late summer 1991), measurements were repeated on subsampled (tagged) natural oak seedlings and on planted oak seedlings.

Analysis of variance (ANOVA) was used to examine treatment effects on regeneration. The main effects tested for were differences between sites. Percent survival data were arcsine transformed to more closely fit a normal distribution. Natural regeneration of northern red oak and white oak were combined, because white oak was absent or rare on some plots. Because planted seedlings were top--pruned, new shoots formed along stems. Therefore, length of the last annual height growth increment was analyzed instead of total height. Finally, X-square tests were used to detect differences in growth form between treatments. In all analyses, the 0.05 level of significance was used.

Results

Planted seedlings. The overall average survival rate for planted northern red oak seedlings was 88% (McNeel 1993). Survival after the first growing season was not significantly affected by site quality or treatment, including use of tree shelters.

Height growth for planted seedlings was significantly greater with tree shelters than without them (figure 1). No other factor (site quality, shelterwood cutting, or understory treatment) was significantly related to height growth (table 1). However, there were significant interactions between site quality and both understory treatment and tree shelters (table 2). Seedlings on both treated and untreated subplots grew higher on good sites than on excellent ones (table 3). On excellent sites, however, understory treatment significantly improved height growth, while the opposite was true on good sites. By contrast, tree shelters significantly improved height growth on both good and excellent sites.

Tree shelters were the only factor to significantly affect the average number of leaves on planted seedlings (figure 2). Sheltered seedlings produced more leaves than unsheltered seedlings, and they tended to have distinct central leaders (figure 3). Seedlings without tree shelters tended to have more intermediate

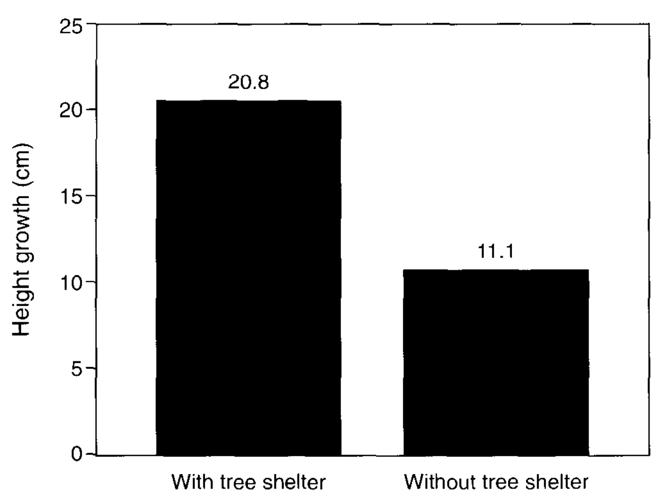

Figure 1—*Tree shelters significantly (P<0.01) improved height growth in planted northern red oak seedlings.*

Table 1—*Height growth of planted northern red oak seedlings after 1 field growing season, by understory treatment, site quality, shelterwood cutting, and use of tree shelters*

	Height growth (cm)			
	With tree shelters[b]		Without tree shelters	
Site/shelterwood[a]	Treated[c]	Untreated	Treated[c]	Untreated
Excellent				
Cut	20.5	18.1	7.1	7.3
Uncut	20.9	21.8	11.6	9.4
Good				
Cut	20.2	22.0	11.1	13.4
Uncut	20.2	22.6	12.2	16.5

[a] Excellent sites = northeast aspects, average site index for northern red oak 27 m at 50 years; good sites = northwest aspects, average site index 23 m. Shelterwood cut = removing overtopped and some intermediate crown-class trees; crown cover reduced to 85% on average.

[b] Cylindrical Tubex tree shelters 1.5 m (5 ft) tall.

[c] Understory treatment = cutting near ground level nonoak stems with dbh < 1.6 cm (0.6 in), then applying trichlopyr or picloram/2,4-D to stumps.

growth form, with less apical dominance. There was, however, a significant interaction effect between shelterwood cutting, understory treatment, and use of tree shelters. Over all sites, 85% of seedlings receiving all three of these treatments had distinct central leaders, compared to only 24% of seedlings receiving none of these treatments.

Natural regeneration. Major competitor species (black cherry and red maple) showed significantly lower early survival rates following understory treatment (table 4). However, survival rates for these species were not significantly related to either site quality or shelterwood cutting.

Table 2—*Analysis of variance of height growth of planted northern red oak seedlings*

Source	df	MS	F	Pr > F
SQ	1	726.23	0.94	0.4038
SC	1	405.82	4.64	0.1202
SQ x SC	1	50.74	0.58	0.5015
UT	1	79.73	4.36	0.0817
SQ x UT	1	319.65	17.50	0.0058
SC x UT	1	19.45	1.06	0.3419
SQ x SC x UT	1	4.51	0.25	0.6368
TS	1	9,678.75	165.61	0.0010
SQ x TS	1	314.89	5.39	0.0206
SC x TS	1	60.24	1.03	0.3100
UT x TS	1	7.57	0.13	0.7187
SQ x SC x TS	1	2.06	0.04	0.8511
SQ x UT x TS	1	11.53	0.20	0.6568
SC x UT x TS	1	29.12	0.50	0.4801
SQ x SC x UT x TS	1	81.51	1.39	0.2377
Error	399	23,318.50	58.44	

Note: SQ = site quality; SC = shelterwood cut; UT = understory treatment; TS = tree shelter.

Table 3—*Height growth of planted northern red oak seedlings after 1 field growing season, by site quality, understory treatment, and use of tree shelters*

	Height growth (cm)	
Treatment	Excellent site	Good site
Understory		
Treated	15.0	15.9
Untreated	14.1	18.6
Tree shelters		
With	20.3	21.3
Without	8.8	13.3

Note: Within columns, means for understory treated/untreated and for tree shelters with/without significantly differ at the 0.05 level.

Mean height of subsampled oaks was 17 cm (6.7 in), whereas subsampled non-oaks averaged 41 cm (16.1 in) in height. There were no significant differences in height related to site quality or shelterwood cutting for either oaks or nonoaks. Although understory treatment significantly reduced the mean height of nonoaks, it did not produce a significant difference in mean height of oaks (figure 4).

Discussion and Conclusions

Of the silvicultural practices examined in this study (shelterwood cutting, understory herbicide treatment, and use of tree shelters), tree shelters were the most effective in promoting the early height growth of

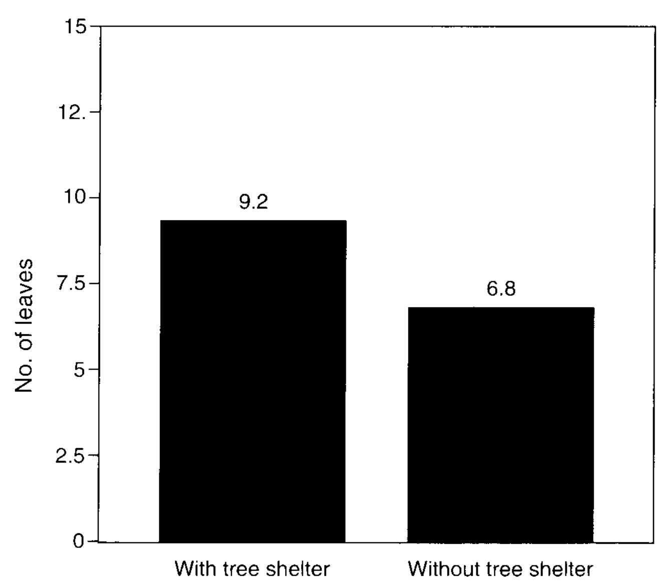

Figure 2—*Planted northern red oak seedlings with tree shelters had significantly (P < 0.01) more leaves than seedlings without tree shelters.*

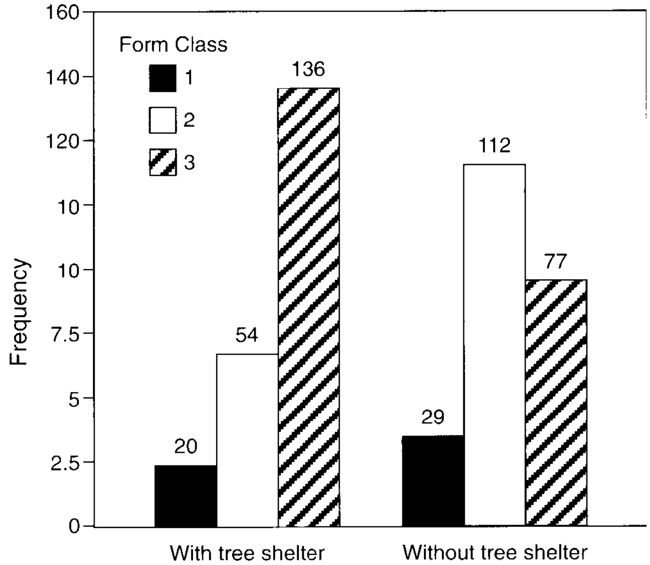

Figure 3—*Frequency of occurence of the three growth form classes from planted northern red oak seedlings with and without tree shelters. Class 1 = flat topped; 2 = intermediate; 3 = with distinct central leader. To a significant (P < 0.01) extent, sheltered seedlings tended to have central distinct leaders.*

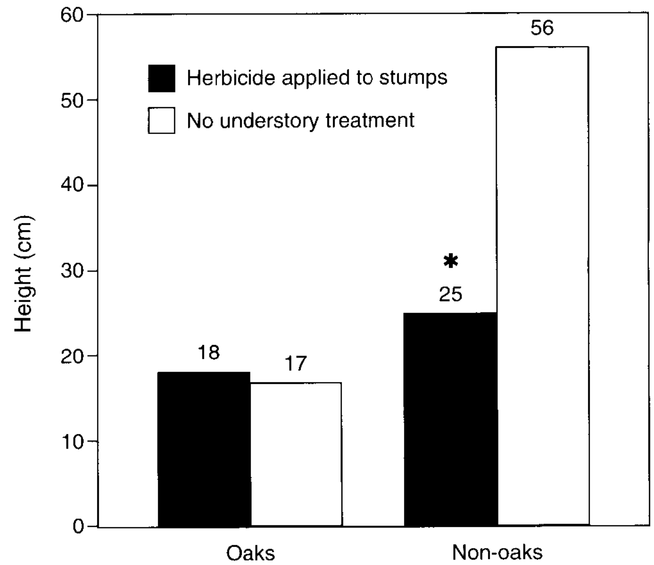

Figure 4—*Mean height of oaks (northern red oak and white oak) and of nonoaks on both untreated subplots and subplots with treated understories (herbicide applied to stumps). Asterisk indicates significant difference (**P** < 0.01) between treated and untreated subplots.*

underplanted northern red oak seedlings on both good and excellent sites. Seedlings with tree shelters also had more leaves and better growth form. Applying herbicide to the stumps of competing vegetation resulted in greater height growth of planted northern red oak seedlings on excellent sites, but not on good sites.

Table 4-*Survival rate of black cherry mid red maple after 1 field growing season, by site quality, understory treatment, and shelterwood cutting*

	Survival rate (%)			
	Black cherry		Red maple	
Site/shelterwood[a]	Treated[b]	Untreated	Treated[b]	Untreated
Excellent site				
Cut	76	93	52	85
Uncut	60	91	56	89
Good site				
Cut	76	85	38	79
Uncut	36	94	9	77
Overal	I 63	91	42	84

Note: For both species, overall means for understory treated and untreated are significantly different from each other at the 0.01 level.

Excellent sites = northeast aspects, average site index for northern red oak 27 m at 50 years; good sites = northwest aspects, average site index 23 m. Shelterwood cut = removing overtopped and some intermediate crown-class trees; crown cover reduced to 85 % on average.

Understory treatment = cutting near ground level nonoak stems with dbh < 1.6 cm (0.6 in), then applying trichlopyr or picloram/2,4-D to stumps.

Although survival of natural seedlings was higher after shelterwood cutting, there was no similar effect on early survival or growth of planted seedlings. Shelterwood establishment cuts were light (no more than 15% canopy cover was removed, on average); more than one removal cut might be necessary to gradually release oaks, stimulating their height growth and helping them against competitors like black cherry and red maple. On excellent sites in the southern Appalachians, frequent light cuts were found to ensure better survival and more rapid height growth of northern red oak seedlings than single heavy cuts (Loftis 1990).

Early survival rates of black cherry and red maple were reduced through understory treatment. Some resprouted, and new establishment occurred, but treatment lowered the average height of these fast-growing oak competitors; although they remained taller on average than oak, their competitive advantage was reduced. After 1 growing season, survival rates of planted northern red oak seedlings were very high. Results indicate that both planted and natural northern red oak seedlings can survive the first growing season, and that use of tree shelters and understory treatment with herbicide can enhance their potential for rapid height growth.

White-tailed deer *(Odocoileus virginianus*) are a major problem in the central Appalachians, and unsheltered seedlings were heavily browsed. The better browse found on excellent sites than on good ones may have attracted more deer, which might explain the greater height growth observed on good sites than on excellent ones for seedlings without tree shelters (table 1). In regions where protection from deer browsing is the major objective, the role of tree shelters in improving survival of sheltered seedlings may be more readily apparent than in this study. On all sites, however, tree shelters not only provided protection from browsing, they also created improved microenvironments for seedling growth.

Underplanting northern red oak appears to be an effective way of supplementing natural regeneration in the central Appalachians. Use of tree shelters can increase the height growth of oak seedlings in this region. However, the high cost of shelters may limit their use in extensive forest management applications.

Address correspondence to David M. Hix, Ohio State University, School of Natural Resources, Columbus OH 43210.

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Effects of Rough Handling on Early Performance of White Pine and White Spruce Seedlings

Ipi Yuyitung, James A. Simpson, and Andrew M. Gordon

Department of Environmental Biology, University of Guelph, Guelph, Ontario, Canada

This study examined the effect on seedling health of dropping standard plastic-lined kraft tree bags containing 3+0 white pine (Pinus strobus *L.*) *and white spruce* (Picea glauca *(Moench) Voss) seedlings from various heights; timing of irrigation after planting was also tested for its effect on seedling vigor. Treatments were evaluated by measuring root growth potential (RGP), and bud flush was assessed at the end of a 3-week period to evaluate its use in predicting stress on seedling performance. White pine seedlings showed a decrease in RGP at every treatment height, but white spruce showed a decrease in RGP at 2 m (the greatest drop distance) only. Irrigating did not increase RGP for either species, although white spruce seedlings exhibited higher RGP than white pine after irrigation. Although irrigation did not affect bud flush in white pine when dropped from 2 m, the percentage of buds that broke dormancy was significantly decreased (P < 0.05). For white spruce seedlings, a downward trend was evident with increasing drop heights, but there was no significant difference at 2 m.* Tree Planters' Notes 45(4):142-146; 1994.

The Canadian forest industry harvested 162 million m^3 (211.7 million yd^3) of wood in 1993 (Anon 1993), but only 500,000 ha (1,235,000 acres) were replanted. The need to maximize survival of outplanted seedlings is underscored by these figures. To increase seedling survival, individual seedlings must be healthy and robust prior to planting. Historical studies have investigated obvious factors affecting seedling health (such as lifting date, Rietveld 1989; or soil temperature, Tabbush 1986), but only a few studies have dealt with damage during seedling transport. These studies (McKay and others 1993, Tabbush 1986, Ritchie 1986, Sharpe and others 1990) suggest that careless handling may have a detrimental effect on seedling growth. McKay and others (1993) studied the effect of dropping seedlings 135 times from heights of 0.1 m (0.3 ft), 1 m (3.3 ft), and 3 m (9.8 ft). Results showed that Sitka spruce *(Picea stitchensis* (Bong.) Carr.) seedlings had lower survival rates as dropping distance increased. Tabbush (1986) reported that dropping Sitka spruce and Douglas-fir *(Pseudotsuga menziesii* (Mirb.)) seedlings from 3 m was as damaging to their health as such deleterious influences as desiccation or extreme temperature. Ritchie (1986) found that placing seedlings in a large metal tumbler to simulate rough handling led to lower initial growth. Many studies have also examined the effect of drought on seedling performance (Coutts 1980, Sands and Nambiar 1984, Deans and others 1990). In a drought, most newly planted seedlings suffer from shock and water stress. Once shoots begin to elongate, an intense water demand is placed on roots. Water uptake can be greatly inhibited by poor root-to-soil contact (Kauppi 1984), which may develop if even a thin layer of air exists around roots. Instead of relying on rainfall, managers can improve survival by irrigating right after planting, because irrigation fills air spaces, establishing a bridge favorable to root growth. This research was designed to

- Examine the vigor of white spruce *(Picea glauca* (Moench.) Voss) and white pine *(Pinus strobus L.)* seedlings after rough handling during shipping from nursery to planting site.
- Study the effect of irrigation in overcoming damage to newly stressed seedlings.
- Evaluate the possibility of using bud flush as a reliable predictor of stress on seedling performance.

Materials and Methods

Plant material. The tree species chosen for investigation were white spruce and white pine, both currently planted and harvested commercially in Ontario. A recent study (Maki 1993) has suggested that white pine is especially sensitive to rough handling and that white spruce is relatively tolerant. Three-year-old bareroot seedlings (3+0) lifted in late fall of 1993 used in this study were acquired from the Ontario Ministry of Natural Resources Nursery in Orono, Ontario.

Stress treatments. Seedlings were placed in a room at 4 ºC (39 ºF) for 1 week after being shipped.

Figure 1—*Dropping a bag of seedlings from 2 meters.*

Sixty seedlings from each species were then randomly selected from the same tree bag. For each treatment, 5 seedlings with roots and shoots that did not appear to be damaged were randomly chosen from the lot of 60 and placed horizontally at the bottom of a standard plastic-lined kraft tree bag. Approximately 20 kg (44.1 lb) of additional seedlings were placed on top, to simulate a full bag of seedlings. A separate bag was then dropped 10 times from each of three treatment heights (figure 1)-1 m (3.3 ft), 1.5 m (4.9 ft), and 2 m (6.6 ft). A control treatment was similarly prepared but not dropped. After treatment, each seedling was planted in a 6-L (6.3-qt) pot using Promix as soil medium and then placed in a greenhouse for 3 weeks.

Irrigation treatments. To study irrigation effects, 50% of the treated seedlings from each species were watered within 4 hours of potting. Because the number of seedlings was uneven, 3 of 5 seedlings per treatment were irrigated within 4 hours of treatment for two blocks, and 2 of 5 seedlings in the third block were irrigated. Remaining seedlings were watered 48 to 52 hours after potting.

Evaluation. Two methods were used to evaluate treatment effects on seedling performance: root growth potential (RGP) and bud break. RGP was quantified by counting the number of new roots produced over the 3-week period, as described by Ritchie (1985). A classification system developed by Burdett (1979) was used, based on number of new roots more than 1 cm long. There were six scores: 0 (no new roots), 1 (new roots less than 1 cm long), 2 (1 to 3 roots more than 1 cm long), 3 (4 to 10 roots more than 1 cm long), 4 (11 to 30 roots more than 1 cm long), and 5 (more than 30 roots more than 1 cm long). Seedlings with high RGP's were judged to have high vigor and performance potential.

Bud break was scored as positive if any new foliage was evident or if buds had expanded and new needle color was apparent. Seedlings were assessed for both bud break and RGP 3 weeks after potting.

Statistical analysis. Data on number of new roots produced and percentage of trees exhibiting bud flush after 3 weeks were analyzed as a three-factor random incomplete block design. The three factors were distance dropped, time of irrigation, and species type. There were three replicates of 16 treatments (2 species x 4 drop heights x 2 irrigation times), with a total of 40 plants per block. All statistical analyses were performed using PC-SAS (SAS 1989).

Results

Stress treatments. Root growth potential for both species declined with increasing distance dropped (table 1), although for spruce the decline was inconsistent. The number of buds that broke dormancy over the 3-week period similarly declined with increasing distance dropped (table 2). However, significant differences in number of trees with bud flush occurred only in white pine. The mean number of new roots produced 3 weeks after dropping was significantly ($P < 0.05$) and substantially less for white pine seedlings dropped from both 1.5 and 2 m; for spruce, no significant ($P < 0.05$) difference was noted among drop heights (table 3).

Table 1—*Median root growth potential of white pine and white spruce seedlings, by height dropped and irrigation treatment*

	Root growth potential			
	White pine		White spruce	
Height dropped (m)	Irrigated within 4 hr.	Irrigated within 48 hr.	Irrigated within 4 hr.	Irrigated within 48 hr.
0	4	3	4	3
1.0	3.5	0	3.5	4
1.5	1.5	0	4	3
2.0	0	1	3	0

Note: 0 = no new roots; 1 = new roots less than 1 cm long; 2 = 1 to 3 roots more than 1 cm long; 3 = 4 to 10 roots more than 1 cm long; 4 = 11 to 30 roots more than 1 cm long; and 5 = more than 30 roots more than 1 cm long.

Table 2—*Rate of bud flush on white pine and white spruce seedlings, by height dropped*

	Bud flush (%)	
Height dropped (m)	White pine	White spruce
0	86 a	53 a
1.0	44 ab	53 a
1.5	36 b	33 a
2.0	44 ab	27 a

Note: Values within columns followed by the same letter are not significantly ($P < 0.05$) different.

Irrigation treatments. Both species exhibited a trend towards general reduction in RGP, number of buds breaking dormancy (table 4), and new root production (table 5) as the interval between time of planting and watering increased. However, these differences were not significant ($P < 0.05$).

Table 3—*Mean number of new roots produced on white pine and white spruce seedlings, by height dropped*

Height dropped	Mean no. new roots	
(m)	White pine	White spruce
0	16a	22a
1.0	8ab	18a
1.5	5b	18a
2.0	2b	12a

Note: Values within columns followed by the same letter are not significantly ($P < 0.05$) different.

Table 4—*Rate of bud flush on white pine and white spruce seedlings, by irrigation treatment*

	Bud flush (%)	
Irrigation	White pine	White spruce
Within 4 hours	57	49
Within 48 hours	49	35

Note: There are no significant ($P < 0.05$) differences between values within columns.

Stress–irrigation interaction. No significant interaction between drop treatment and timing of irrigation was observed ($P < 0.05$). However, early irrigation may ameliorate damage from rough handling, at least in white pine (table 1). For spruce, greatest reduction in RGP occurred when seedlings were dropped from 2 m (6.6 ft) and irrigation was delayed for 48 hours.

Discussion

Dropping seedlings reduced RGP in both species, although white pine appeared to be more sensitive to rough handling than white spruce. However, this difference in root growth may be a function of an unequal number of initial roots (lateral and fine roots) between the two species or a difference in physiological response rather than a response to environmental factors: white pine may have appeared more sensitive because its RGP was lower to begin with than that of white spruce. Moreover, the seedlings in this experiment, taken as they were from the bottom of the dropped bags, would likely have been most severely impacted. Other seedlings in the bag may not have sustained as much damage.

In his studies, Tabbush (1986) found that Douglas-fir began with a lower RGP than Sitka spruce. He also confirmed that peak RGP for Douglas-fir was in midwinter, whereas the RGP peak for Sitka spruce was in late summer. Sharpe and others (1990) observed a

Table 5—*Mean number of new roots produced, by irrigation treatment*

	Mean no. of new roots	
Irrigation	White pine	White spruce
Within 4 hours	11	21
Within 48 hours	4	14

Note: There are no significant ($P < 0.05$) differences between values within columns.

similar disparity in RGP between species under the same treatment. In all treatments, Sitka spruce had at least 5 times more roots than Douglas-fir.

The negative relationship of RGP to increasing drop heights observed in this study was expected. Observations made by Maki (1993) working with black spruce (Picea mariana (Mill.) B.S.P.) seedlings at the Ontario Forest Research Institute (Saint Ste. Marie, Ontario) dropped at the same frequency and height range support our results. Maki reported mean RGP's of 4.6, 4.9, and 3.9 for black spruce seedlings dropped 10 times from heights of 0 m, 0.5 m (1.6 ft), and 2 m (6.6 ft), respectively. A study by Deans and others (1990), in which the seedling was struck with the toe of a boot to knock off dirt after lifting, also showed a decrease in RGP. In that study, the RGP of roughly handled Sitka spruce seedlings was only 15% of the RGP found in control seedlings.

Because there was no apparent mechanical damage to roots or shoots from the treatment in the present study, reduction in RGP may be due to cytological damage. Jaffe (1980) measured ethylene production of vascular plants that had undergone mechanical stimuli and observed a change in the permeability of the cell membrane and an increase in ethylene production. Because ethylene plays a role in producing phytoalexin-like stress metabolites that reduce growth (Takahashi and Jaffe 1984), it is likely that mechanical stress increases ethylene production and subsequently inhibits growth.

A study by McKay and others (1993) reported an increase in electrolyte leakage and respiration levels in Sitka spruce seedlings subjected to several (1, 5, or 15) drops from 10 cm (3.9 in), 100 cm (39 in), and 300 cm (390 in). This suggests that cell membranes were damaged, resulting in impaired transmembrane electrolyte transport.

Irrigating planted seedlings after stress may have a mitigating effect, especially for white pine, and further tests should be carried out to define this effect. RGP was less in plants irrigated 48 hours after being dropped than in those irrigated 4 hours after dropping (table 1), which may be of ecological significance, even though statistical testing was not done on this class data.

Water is obviously important to plants under stress, especially when seedlings are newly transplanted (Rietveld 1989, Coutts 1980). Stressed seedlings show decreased transpiration rates and a partial closure of the stomata (Coutts 1980), and these effects may last for a day or longer, depending on severity of root disturbance.

Spruce needles are shorter and have a thicker waxy layer than pine needles. This provides spruce with a higher water stress resistance, indirectly seen in the results: irrigation of white spruce resulted in no significant difference in RGP between 4-hour and 48-hour treatments (unlike irrigation of white pine).

Conclusions

Results confirm that rough handling can have a negative effect on seedling growth. White pine seedlings showed a decrease in RGP after drops of 1 m (3.3 ft) or more, and white spruce seedlings showed a similar decrease at 2 m (6.6 ft). The mean number of new roots produced 3 weeks after dropping also declined in both species, although the decline was significant ($P < 0.05$) only in white pine. Results underscore the need for careful handling of seedlings during transport from nursery to planting site.

The greater sensitivity of white pine than white spruce to rough handling can be used in practice to develop different handling procedures for the two species. For example, irrigation of white pine seedlings may be useful in offsetting handling stress and improving survival.

Although RGP has been widely accepted as a sensitive measure of seedling vigor, it can be timeconsuming and requires destructive sampling. Bud flush provides a quick, nondestructive method of assessing seedling vigor. It has the advantage over methods such as dormancy release index (DRI, or the number of days after planting before bud flush) of requiring only one visit per plant. Evaluating bud flush might be an excellent method if it could be used to assess the vigor of outplanted seedlings. However, further evaluation of bud breakage in relation to mechanical stress and relative to the length of time required for flushing in individual species is required to refine the technique.

Results pertain only to seedlings taken from the bottom of tree bags. Further research is needed to evaluate the impact of rough handling on the "average" seedling not found at the bottom of the bag.

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Address correspondence to A. M. Gordon, Department of Environmental Biology, University of Guelph, Guelph, ON NIG 2W1 CANADA.

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