Oxyfluorfen Shows Promise in Lodgepole Pine Seedbeds

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The herbicide oxyfluorfen was applied at 0.75 and 1.50 pounds per acre to lodgepole pine (Pinus contorta *Dougl. ex Loud) nursery beds. First-year treatments reduced seedling heights. Second-year applications had little effect on seedling heights or densities. Oxyfluorfen reduced weeding times by 76%.* Tree Planters' Notes 38(2):03-9 ; 1988.

Oxyfluorfen [2-chloro1-(3-ethoxy-4-nitrophenoxy)-4(trifluoro-methyl)benzene] is a broad-spectrum selective herbicide of the diphenylether group. Richardson and others (11) recommended it for use in several crops: soybeans, cotton, peanuts, wheat, rice, legumes, sugar beets, and tree and vine plantation crops.

It was used experimentally in seedbeds of southern pines beginning in 1976 and was registered by the Environmental Protection Agency in 1979 (14). Since then, southern nurserymen have used oxyfluorfen in pine seedbeds for both preemergence and postemergence treatments (15). It is effective in controlling most broadleaf weeds and many grasses found in forest nurseries (6, 7, 14, 15).

In comparisons with other diphenylether herbicides, Yih and Swithenbank (18) found that oxyfluorfen had more than 10 times greater activity than nitrofen and fluorodifen, and a broader spectrum of activity as well. This increase in activity means a significantly lower rate of chemical application and a reduced possibility of contamination in the environment.

The herbicidal activity of oxyfluorfen and other diphenylether herbicides takes place through lipid peroxidation, which damages cellular membranes, especially those of organelles (3, 6, 8, 10, 12). Light is essential in the activation process of oxyfluorfen (3, 7, 8, 9, 17, 18); in fact, darkness completely inhibits the herbicide.

Fadayomi and Warren (3) reported that oxyfluorfen is inactivated in muck soils. There is little inactivation by clays, and in data presented by South and Gjerstad (14) there is no apparent relationship between weed control or phytotoxicity and percentage of organic matter in the soil.

A few studies have tested oxyfluorfen on pine seedbeds. South and Gjerstad (14) conducted pre-emergence tests at 11 southern pine nurseries. They found that application rates of 0.5 to 1.0 pounds of active ingredient per acre (0.56 to 1.12 kg/ ha) provided good weed control without damage to loblolly (*Pinus taeda* L.), slash (*Pinus elliottii* Engelm.), shortleaf (*Pinus echinata* Mill.), longleaf (*Pinus palustris* Mill.), Virginia *(Pinus virginiana* Mill.), and eastern white pine (*Pinus strobus* L.). Generally, postemergence applications of 0.5 to 1.0 pounds per acre (0.56 to 1.12 kg/ha) provided 55 to 84% weed control for the remainder of the handweeding season. Again, no injury to pine seedlings was observed.

South and Mexal (15) showed that at the pre-emergence rate of 0.5 pounds per acre (0.56 kg/ha), oxyfluorfen did not significantly reduce early growth of loblolly pine seedlings, but at 1.0 pounds per acre (1.12 kg/ha) average seedling heights were significantly reduced. Neither concentration had significant effects on seedling densities by the 25th day after sowing. In growth chamber tests, a rate of 1.39 pounds per acre (1.56 kg/ha) applied before germination produced white lesions on the stems of a third of the seedlings.

Abrahamson and Burns (1) tested oxyfluorfen at four forest nurseries of the Great Plains. They found that at 0.25 pounds per acre (0.28 kg/ha) a preemergence application did not reduce weed growth. Survival of ponderosa (*Pinus ponderosa* Dougl. ex Laws.), loblolly, Austrian (*Pinus nigra* Arnold), and lodgepole (*Pinus contorta* Dougl.) pine treated with oxyfluorfen was not statistically different when compared to untreated plots.

Yih and Swithenbank (18) found oxyfluorfen close to 100%

effective in greenhouse weed control tests. The herbicide was applied at both pre-emergence and postemergence timings and at four concentrations from 0.11 pounds per acre (0.125 kg/ha) to 0.89 pounds per acre (1.0 kg/ha).

Turner and Richardson (16) applied oxyfluorfen at 0.44 pounds per acre (5.0 kg/ha) in postemergence applications to lodgepole pine seedlings in pots. They found no significant phytotoxic effects.

In tests done by Heidmann and Haase (5), oxyfluorfen at a rate of 0.5 pounds per acre (0.56 kg/ha) was effective in controlling weeds when applied after seeding. Postemergence applications of up to 1.5 pounds per acre (1.68 kg/ha) did not significantly reduce weed growth. Damage to ponderosa pine seedlings was variable using 0.5 pounds per acre (0.56 kg/ha) pre-emergence. Postemergence applications did not reduce the mean density of ponderosa pine seedlings in the nursery bed.

Schlesselman and Lange (13) demonstrated that a 3-day delay in irrigation after pre-emergence applications of oxyfluorfen can cause a reduction in the herbicide's residual effect. Further, temperature has the most pronounced effect. Applications in the hot summer months have less residual effect than in the fall, when temperatures have cooled off.

Oxyfluorfen is an effective herbicide for controlling weeds and at much lower application rates than many other herbicides. However, further study is required before it can be used with confidence on lodgepole pine. This paper reports the results of phytotoxicity and weed control tests in lodgepole pine seedbeds at Lucky Peak Nursery near Boise, ID.

Methods

The study had two parts: 1) A phytotoxicity test to determine the effects of pre-emergence and postemergence applications of oxyfluorfen on lodgepole pine seedling survival and growth, and 2) a weed control test to find out what effect oxyfluorfen would have on the time required to hand weed nursery beds.

Phytotoxicity test. The plots were set up in a randomized complete block with six replications. Each replication contained 10 combinations of dosage and time of application plus one untreated control plot. Each plot was 3 feet (0.91 m) long with a 1-foot (0.30-m) buffer strip in between. All plots were in a single nursery bed 4 feet (1.2 m) wide. Table 1 explains the 11 treatments.

Table 1—*Concentrations and timing of the oxyfluorfen treatment*

	First year				Second year			
	April 29[a]		June 16[b]		April 17		June 26	
	0.75 lb/acre	1.50 lb/acre	0.75 lb/acre	1.50 lb/acre	0.75 lb/acre	1.50 lb/acre	0.75 lb/acre	1.50 lb/acre
Phytotoxicity								
1× PS (1)	•							
1× PS (1 + 2)	•				•		•	
2× PS (1)		•						
2× PS (1 + 2)		•				•		•
PS + PG (1)	•		•					
PS + PG (1 + 2)	•		•		•		•	
1× PG (1)			•		A		A	
1× PG (1 + 2)			•		•		•	
2× PG (1)				•				
2× PG (1 + 2)				•		•		•
No treatment								
Weed control								
1× PS	•				•			
1× PS + 1× PG	•		•		•		•	
No treatment								

[a]Oxyfluorfen applied 1 day after sowing.
[b]Oxyfluorfen applied 48 days after sowing.
PS = postseeding, PG = postgermination.

We applied oxyfluorfen in a 4.5-foot (1.4-m) swath using an AZ small-plot pressurized sprayer. The emulsifiable concentrated herbicide was diluted in a water carrier at a volume equivalent to 85 gallons per acre (127 liters/ha) or 100 ml per 3-foot (0.91-m) plot. Preemergence treatments were applied within 2 days after sowing (April 29, 1983). Postemergence sprays were applied 4 to 5 weeks after seedling emergence (June 16, 1983). We made second-year applications on April 17 and June 26, 1984. Application rates were 0.75 pounds of active ingredient (a.i.) per acre (0.84 kg/ha) (1 x concentration) and 1.5 pounds a.i. per acre (1.69 kg/ha) (2 x concentration).

Nursery personnel conducted all normal cultural activities as scheduled except use of herbicides and weeding.

To compare each treatment with the control plot we used a herbicidal damage rating scale (2) at the end of the first and second growing seasons. At the same time, we counted the number of live seedlings and measured average heights in three 1-foot (0.30-m) sample rows in every plot. At the end of the second growing season we lifted the trees in all three sample rows from which we randomly selected 10 trees to measure dry weights of shoots and roots. Data were analyzed using analysis of variance and single degree of freedom comparison of means (4).

Weed control test. In a seedbed adjacent to the phytotoxicity test we established treatment plots for the weed control test in a randomized complete block with three replications. Within a block, we put two treatments and one control plot. Each plot was 20 feet (6.1 m) long, and plots were separated by a 1-foot (0.30-m) buffer strip. The application timing and herbicide dosage are explained in table 1. Spray methods and application dates and rates were the same as for the phytotoxicity tests.

Table 2—*Comparison of treatment means with control plot means for second-year phytotoxicity data for oxyfluorfen on lodgepole pine*

Treatment	Mean tree height (cm)	Mean No. of seedlings/ ft of row	Mean damage rating[a]	Mean top dry weight (g)	Mean root dry weight (g)
1 × PS (1)	12.73 **	8.48NS	7.50**	5.60 NS	2.76 NS
1 × PS (1 + 2)	11.62 **	8.78NS	7.33**	5.31 NS	2.54 NS
2 × PS (1)	10.83 **	5.60**	5.67**	5.27 NS	3.11 NS
2 × PS (1 + 2)	10.43 **	5.07**	5.50**	5.41 NS	3.01 NS
1 × PG (1)	12.73 **	15.40*	9.33NS	4.34 NS	2.16 NS
1 × PG (1 + 2)	12.2 **	12.73NS	9.33NS	4.48 NS	2.40 NS
2 × PG (1)	11.77 **	12.38NS	9.17NS	4.46 NS	2.31 NS
2 × PG (1 + 2)	11.78 **	10.57NS	8.83*	4.31 NS	2.35 NS
PS + PG (1)	10.93 **	8.8 NS	6.67**	4.99 NS	2.56 NS
PS + PG (1 + 2)	11.00 **	6.93*	7.00**	5.01 NS	2.81 NS
No treatment	14.83	11.17	10.00	5.50	2.64
Total average	11.86	9.63	7.85	4.97	2.61

* = Significantly different from the "no treatment" mean (α = 0.05) using the single degree of freedom comparison *(4)*.
** = Significantly different from the "no treatment" mean (α = 0.01) using the single degree of freedom comparison *(4)*.
NS = No significant difference from the "no treatment" mean (α = 0.05) using the single degree of freedom comparison *(4)*.
[a]Damage rating is based on "no treatment" plots and ranges from 10 (no damage) to 1 (complete mortality).

Results

Phytotoxicity tests. Damage by the 1.5 pound a.i. rate was more severe than the 0.75 pound a.i. rate (table 2). Plots sprayed with the higher concentration of herbicide after seeding showed a significant reduction in number of seedlings. Likewise, the plots sprayed at all four application times had significantly fewer trees than control plots. The postemergence plots sprayed with 0.75 pound per acre had significantly more trees. All spray treatments reduced height growth of the seedlings. The subjective damage ratings show that all postseeding treatments reduced the overall growth and survival, as did the 1.5-pound rate applied at a postemergence timing both years. None of the treatments significantly affected the mean dry weights of tops or roots.

When compared, first-year treatment means were consistent with second-year measurements given in table 2.

Weed control tests. I n the weed control test (fig. 1) the plots with 0.75 pound per acre applied in April of both years took 66% less time to weed than did the control plots. The other treatment, in which the same rate was applied in April and June each year, took 76% less weeding time than the control. The differences in weeding times compared to untreated plots were statistically significant (a = 0.01). Most of the weeding time came in the second year. Even on control plots, there were few weeds the first year.

Discussion and Conclusions

Most of the phytotoxic effects of the oxyfluorfen applications took place in the first growing season. Mortality was high only on plots sprayed with the 1.5 pounds per acre concentration of herbicide immediately following seeding. Figure 2 shows how little seedling density changed for most treatments between the first and second years. Also, there is little difference in mean density between plots that

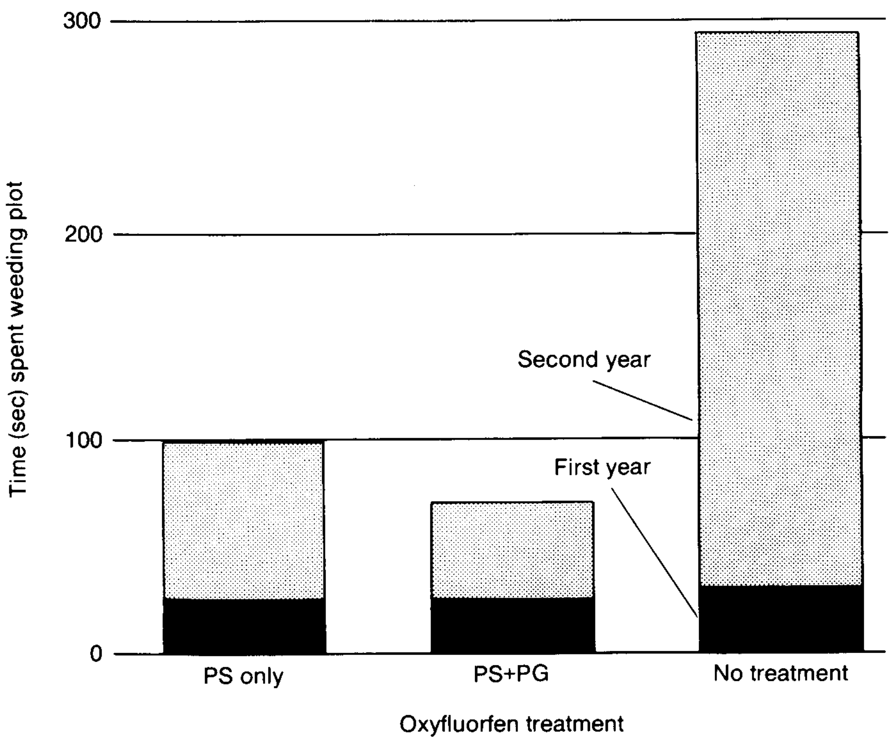

Figure 1—*Average weeding times on 30-foot test plots. The pre-emergence treatment plots were sprayed with oxyfluorfen in April of both years. The pre-emergence and postemergence plots were sprayed in April and June of both years. All applications were at 0.75 pound per acre.*

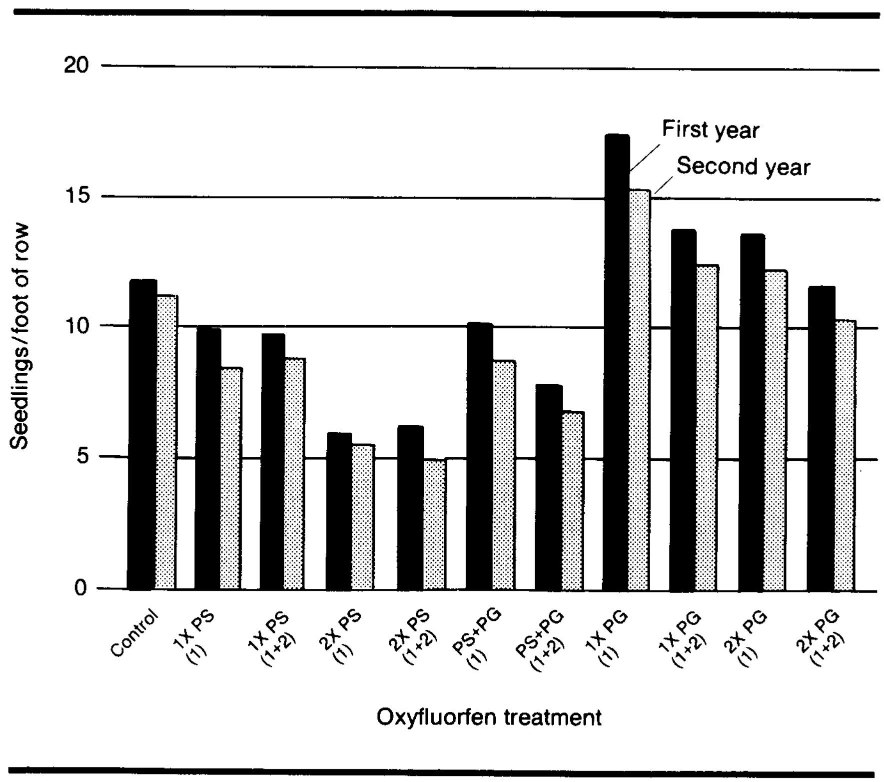

Figure 2—*Effect of oxyfluorfen treatments on density of live lodgepole pine seedlings in the nursery bed for the first and second growing seasons. Control = no treatment, 1× = 0.75 pound per acre active ingredient, 2× = 1.50 pound per acre active ingredient, PS = postseeding, PG = postgermination, 1 = first year only, 1 + 2 both first and second year. See table 1 for more information on timing of applications.*

received second-year applications and those that did not. The one exception is on the plots recorded. Again, all nursery operations except use of herbicides were conducted by nursery personnel when required.

All plots were hand weeded twice during both growing seasons, and weeding times were that had a 0.75-pound-per-acre spray all four times. They showed a slight reduction in seedling density the second year compared to the control.

The first-year postemergence treatment shows a higher mean seedling density than the control because of a much higher sowing density on one of the plots. Weed competition was not an important factor in reducing seedling density. Figure 3 compares four plot treatments as viewed from above and illustrates the reduction in seedling density from the control, to the 2 x postemergence, to the 1 x pre-emergence and postemergence, to the 2 x pre-emergence applications.

The average height of seedlings was diminished by all of the oxyfluorfen spray schedules in this study and at both concentrations. The highest average reduction in height came on plots with pre-emergence applications. The 2 x concentration of oxyfluorfen seemed to have more detrimental effects on seedling height, and again, most of the herbicide damage was done in the first growing season.

The damage ratings emphasize what has been shown in the seedling heights and plot densities. Pre-emergence sprays have the most phytotoxic effects on lodgepole pine seedlings. The herbicide treatments seem to have little effect on the dry weight of seedlings because even though control plot trees were taller, the oxyfluorfen generally reduced the density on the other plots. The low-density plots produced bushier trees with larger calipers. This increased caliper compensated for the shorter height in the dry weight measurements.

When Abrahamson and Burns (1) tested oxyfluorfen on lodgepole pine seedbeds, their results were similar. However, at

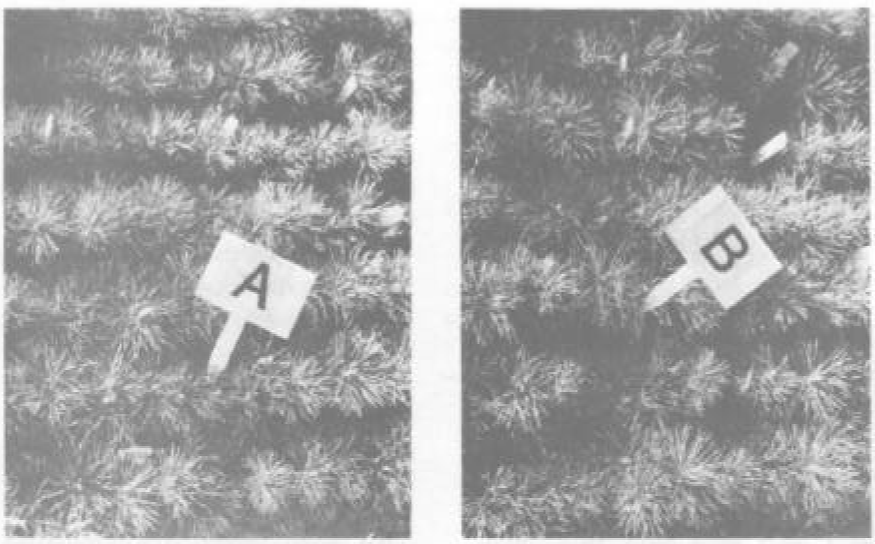

Figure 3—Overhead view of four plots, each with a different first year oxyfluorfen treatment. None of the plots were sprayed during the second year. No treatment (A). 1.5 pounds per acre postemergence (B).

the reduced rate of 0.25 pound per acre, reductions in seedling heights and survivals were not statistically significant. Likewise, when Turner and Richardson (16) applied oxyfluorfen at 0.44 pound per acre pre-emergence to lodgepole pine in a greenhouse, they found no significant phytotoxic effects.

Although oxyfluorfen was effective in controlling weeds in this study, weed growth was not heavy, even on the control plots. The times here translate into 2.7 worker hours to weed 1,000 linear feet of control plot compared to 0.6 and 0.9 worker hours per 1,000 feet of sprayed plots. Because seedbeds are fumigated after each crop of seedlings, weed growth was especially sparse the first growing season. The April application was effective in preventing weed growth, and June applications further improved the weed control a little bit.

Most other studies also report more effective results using pre-emergence oxyfluorfen sprays compared to postemergence. In concentrations of 0.5 to 1.0 pound per acre (14), 0.25 pound per acre (1), and 0.11 to 0.89 pound per acre (18) oxyfluorfen was successful in weed control when sprayed pre-emergence. Postemergence tests in these three studies give mixed results.

It appears that oxyfluorfen can control weeds in nursery beds at Lucky Peak Nursery. Weeding times were reduced by 66% with a pre-emergence spray of 0.75 pound per acre and a postemergence spray in April of the second year. The weeding time decreased an additional 10% by spraying again in June of both years. However, oxyfluorfen spray damaged lodgepole pine seedlings, especially when applied as a pre-emergence spray.

Nursery managers could avoid most of the lodgepole pine seedling damage by waiting until the second year to spray with oxyfluorfen. We saw no additional drop in survival and height growth after the first year. To use only hand weeding in the first year may also be the most economical method. Few weeds grew during the first year, even on control plots.

The 1.5-pounds-per-acre concentration of oxyfluorfen was stronger than needed. It caused more seedling damage than did the 0.75-pound-per-acre concentration. In fact, concentrations less than 0.75 pound per acre may be adequate in weed control and cause minimal damage to seedlings.

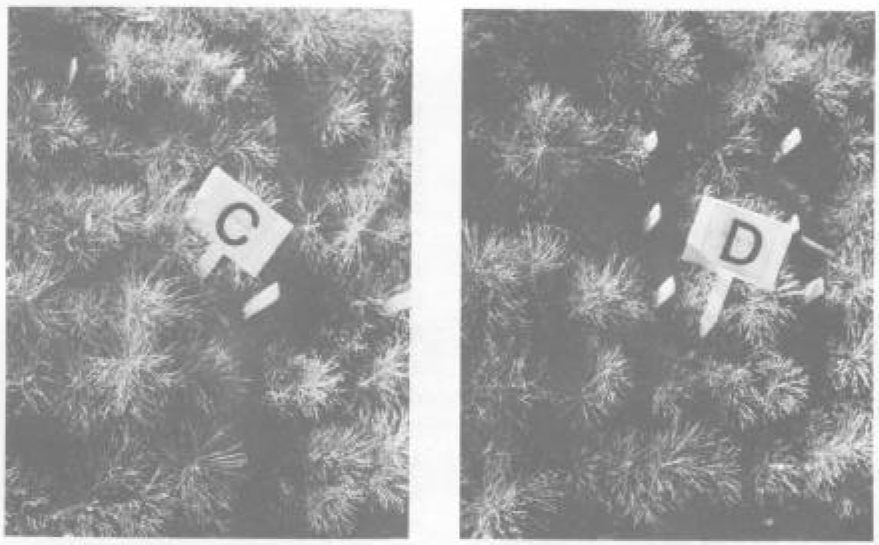

Figure 3—*0.75 pounds per acre pre-emergence and postemergence* **(C)**. *1.5 pounds pounds per acre pre-emergence* **(D)**.

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Survival of Loblolly Pine Seedlings Planted on Areas Fall-Sprayed With Soil-Active Herbicides

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Results of two studies simulating site preparation by fallspraying with soil-active herbicides are presented. None of the treatments affected survival or growth of loblolly pine (Pinus taeda *L.) seedlings planted 2 months after spraying.* Tree Planters' Notes 39(2):10-12; 1987

Site preparation with herbicides before planting of pine seedlings has traditionally been accomplished during the spring and early summer. Kidd and others (1, 2) reported that fall applications may be a desirable alternative to treatments earlier in the year. They suggested several advantages of fall treatments: (1) fall spraying can prevent the possibility of a year's delay in treatment and planting due to wet conditions that would impede logging in time for spring treatments; (2) where sensitive agricultural crops or gardens are located near treatment areas, fewer susceptible plants are present during the fall; and (3) more herbicide applicators are available in the fall than in the spring. Finally, these researchers obtained excellent results with fall applications of picloram (Tordon) and triclopyr (Garlon).

Applying soil-active herbicides in the fall for site preparation raises the question of whether residual chemicals will kill pine seedlings planted the following winter. Two experiments were installed in southeast Arkansas to answer this question.

Methods and Study Areas

Experiment 1. An area on the school forest at the University of Arkansas at Monticello was mowed in preparation for the study. The area is level, and the soil is Henry silt loam (Typic Fragiaqualf). This poorly drained soil has a strong fragipan within 18 to 24 inches of the surface that impedes percolation of water. A pine plantation on the area had been clearcut 2 years earlier, and the principal vegetation consisted of tufts of broomsedge *(Andropogon virginicus* Thus, there was little vegetation on the area to intercept the spray.

Following mowing, twenty-one 20-by 20-foot-square plots were outlined with a string. The seven treatments listed in table 1 were applied to the plots on October 25, 1982. (Each of these chemicals exhibits varying degrees of soil activity.) The measured amounts of herbicide were applied on each plot with a backpack sprayer in enough water to equal 1 gallon of spray material, or at the rate of 110 gallons per acre. Each treatment was replicated three times.

On December 15, 51 days after treatment, 25 loblolly pine *(Pinus taeda* L.) seedlings were handplanted on each plot. The combination of late spraying and early planting provided for a "worst possible" scenario. Heavy rains between the time of spraying and planting resulted in flooding of the low-lying, flat area. Water was standing in depressions on the plots when the seedlings were planted. The soil was saturated until late the following spring, but there was no evidence of movement of herbicides off the plots, as evidenced by the sharp delineation of grass kill.

Survival and heights of seedlings were measured in the late fall of 1983 after one growing season and evaluated by ANOV, with differences being tested for significance at the 0.05 level.

Experiment 2. Because of the extensive flooding encountered in experiment 1, a second study was installed on an area with better drainage, having a gentle slope, on the Crossett Experimental Forest during the fall of 1983. The soil there is Bude silt loam (Glossaquic Fragiudalf), having a week fragipan at 26 to 30 inches. Plots were on a mowed area that consisted primarily of carpetgrass *(Axonopus affinis).* The area was disked to expose mineral soil immediately before treatment.

Plot layout, spraying, and planting procedures were the same as in experiment 1, except that additional treatments were added as listed in table 2. The plots were treated on October 25, 1983, and seedlings were planted 72 days later, on January 5, 1984. Inclement weather and frozen soil prevented earlier planting. Heights of all seedlings were measured immediately after planting and averaged 0.8 foot. First-year height growth and survival were measured after one growing season, on February 22, 1985, and subjected to ANOV, with differences being tested for significance at the 0.05 level.

Results

Experiment 1. There were no significant differences among treatments in percentage of survival or seedling heights. Survival averaged 82% (table 1), which was surprisingly high in view of the extended period of flooding during the winter and spring. Water was still standing on the plots on June 23. Seedling heights averaged only 1.0 foot a year after planting. This low figure was undoubtedly the result of flooding rather than any treatment effect. Seedling heights were not measured at the time of planting, but seedlings were quite uniform, averaging about 9 inches in height. Thus, height growth was only about 3 inches during the first year.

Experiment 2. Survival and height growth were good on all plots, and there were no significant differences due to treatment effects. Survival ranged from 88 to 97% and averaged 92% (table 2). There was no evidence of herbicide toxicity for any of the treatments. Height growth during the first year ranged from 1.1 to 1.3 feet and averaged 1.2 feet. After 1 year in the field, seedlings averaged 2 feet in height and 0.4 inch in diameter near the groundline.

Table 1—*Survival and first-year heights of loblolly pine seedlings planted 51 days after plots were sprayed with soil-active herbicides (experiment 1)*

Chemical	Rate (lb/acre)	Survival (%)	Total height (ft)
Control	—	79	1.0
Dicamba (Banvel)	4	92	1.0
Dicamba	8	72	1.0
Fosamine (Krenite)	12	75	1.0
Hexazinone (Velpar)	4	85	1.0
Picloram + 2,4,-D amine (Tordon 101)	1 + 4	91	1.1
Triclopyr (Garlon)	4	77	1.0
Average		82	1.0

Table 2—*Survival and first-year height growth of loblolly pine seedlings planted 72 days after plots were sprayed with soil-active herbicides (experiment 2)*

Chemical	Rate (lb/acre)	Survival (%)	Height growth (ft)
Control	—	93	1.1
Dicamba (Banvel)	4	96	1.2
Dicamba	8	88	1.1
Dicamba + 2,4-D amine	3 + 5.7	96	1.2
Dicamba + triclopyr	4 + 2	95	1.3
Fosamine (Krenite)	12	89	1.1
Hexazinone (Velpar)	4	90	1.1
Picloram + 2,4-D amine (Tordon 101)	1 + 4	97	1.1
Triclopyr (Garlon)	4	88	1.2
Average		92	1.2

Conclusions

The results of these two experiments demonstrate that seedlings can be safely planted in areas sprayed with these tested soil-active herbicides within 2 months after treatment. This should allow ample time for herbicide degradation, because most fall applications of herbicides for site preparation in the South are made before October 15 and pine seedlings are usually not planted before mid-December.

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Screening of Three Pre-emergence Herbicides for Intensive Plantation Management in Michigan

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*Three herbicides were applied to newly planted seedlings of six species—European larch (*Larix decidua *Mill.), Kellogg hybrid pine (*Pinus nigra *Am.* X. P. densiflora *Sieb. and Zucc.), northern red oak (*Quercus rubra *L.), tag alder (*Alnus *B. Ehrh. spp.), black locust* (Robinia pseudoacacia *L.), and ailanthus (*Ailanthus altissima *(Mill) Swingle). Survival and growth and the effectiveness of weed control were assessed at the end of the first growing season. Simazine was the only general purpose herbicide tested that was nontoxic and effective for all species. Diphenamid was safe but ineffective, and hexazinone was effective but safe only at low levels for tag alder and Kellogg hybrid pine.* Tree Planters' Notes 39(2):13-18; 1988.

The suppression or elimination of weed competition can be directly linked to improved crop growth and yield. This axiom is as true in silviculture as in agriculture and horticulture. Many authors have documented impressive improvements in survival and early growth of planted seedlings or cuttings when weed control is maintained (3, 4). Weed control is, therefore, generally considered to be an integral part of intensive forest management of conifers and is requisite for hardwoods (8). The question, then, is how best to achieve good weed control at a reasonable cost without damaging the crop or the site.

The first step to weed control is the removal of existing site vegetation before planting. This can be done in a variety of ways but was done chemically for these investigations. The second step to weed control involves preventing new weeds from invading the planted site, and competing with the crop. This can be done chemically in one of three ways: 1) Use of an herbicide for site preparation that has a residual effect in the soil and is toxic to weeds but not the crop. 2) Use of postplanting pre-emergence herbicides to prevent the germination of weed seeds. 3) Use of postemergence herbicides to kill weeds, either by selective phytotoxicity or by directing application only to the weeds.

The distinction among the methods listed above varies with the characteristics of the herbicides. Hexazinone, for example, acts as a site preparation herbicide that is persistent in the soil and as a selective postemergence herbicide. Simazine and diphenamid, on the other hand, act strictly as in post-planting pre-emergence herbicides, only affecting germinating weed seeds. This investigation was conducted to test the suitability of these three herbicides for use

Table 1—*Herbicides and rates of application used to over-spray dormant newly planted seedlings*

Common name	Application rates kg/ha (lb/acre) ai: Low	Medium	High	Dilution in water liter (gal)
Diphenamid[a]	6.7(6)	9.0(8)	11.2(10)	114 (30)
Simazine[b]	2.2(2)	4.5(4)	6.7(6)	151 (40)
Hexazinone[c]	1.1(1)	1.7(1.5)	2.2(2)	189 (50)

[a]Enide 90 WP, NOR-AM Agricultural Products.
[b]Princep 4L, Ciba-Geigy Corp.
[c]VELPAR L, E.I. duPont de Nemours and Co.

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in post-planting weed control on several forest tree species for which little quantitative information was available.

Methods

Herbicides tested. Three herbicides were chosen for testing: diphenamid, simazine, and hexazinone (table 1). Past experiences with diphenamid and simazine have shown that both are reasonably nontoxic to most woody crops and provide good control of most common weeds (3, 5, 7, 9). Hexazinone is highly phytotoxic, especially to hardwood species, but does show selectivity for some conifer species. It was included to test its effect when sprayed over dormant seedlings. The dual action of hexazinone, as a persistent site-preparation herbicide and as a partially selective postemergence herbicide, make it doubly useful in weed control programs: it can eliminate the need for additional pre-emergence herbicides, or it can be used for overspraying to release seedlings from competing weeds. Each herbicide was applied at three rates: 1) the optimal rate recommended on the label, 2) a suboptimal rate, and 3) a superoptimal rate (table 1).

Seedling production. Six species were selected to represent a range of growth types: European larch (*Larix decidua* Mill.), Kellogg hybrid pine (*Pinus nigra* Am. X. P. *densiflora* Sieb. and Zucc.), northern red oak (*Quercus rubra* L.), tag alder (*Alnus* B. Ehrh. Spp.), black locust *(Robinia pseudoacacia* L.), and ailanthus (*Ailanthus altissima* [Mill.] Swingle). Red oak is commercially important in the Lake States, and the others have been shown to have potential for future use. Tree improvement programs are currently under way for these species at Michigan State University.

Black locust seedlings for this study were produced in nursery beds as standard 1+0 stock during 1984. Containerized seedlings of all the other species mentioned above were produced during 1984. Seeds were sown in poly-coated paper plant bands 5 cm x 5 cm x 29 cm in size. The bands were filled with a medium composed of three parts of peat moss, one part of vermiculite, and one part of per-lite. Seedlings were grown for 4 months under 16-hour photoperiods in the greenhouse and then moved outside to acclimate under 50% shade in the fall of 1984. The seedlings were mulched and held in covered overwintering houses until the spring of 1985, when they were removed from their bands, barerooted, sorted, and stored in a cold room before planting.

Site selection and planting. A site in East Lansing, MI, was selected for the test planting. Soil from the test site was analyzed by the Michigan State University crop and soil science department (table 2). The site was mowed during the summer of 1984 and sprayed with 3.4 kg/ ha (3 pounds per acre) glyphosate (ROUNDUP) to kill weed regrowth in the early fall of 1984. The glyphosate treatment was repeated the following spring, 2 days before planting, to ensure

Table 2—*Analysis of soil in the Ap horizon of the planting site in East Lansing, MI*

	Analysis
Texture	
Soil series	Owosso-Marlette sandy loam
Sand fraction	63%
Silt fraction	18%
Clay fraction	19%
Organic matter	1.4%
Chemical characteristics	
pH	5.3
P content	27 kg/ha (24 lbs/acre)
K content	104 kg/ha (93 lbs/acre)
Ca content	717 kg/ha (640 lbs/acre)
Mg content	100 kg/ha (89 lbs/acre)

total preplanting weed control.

Seedlings were planted on June 6, 1985, with a subsoiling tree planter, which made a 30-cm-deep (12-inch-deep) planting slit. The plantation was established in a split-plot complete randomized block design with 6 blocks using 4-tree linear subplots for ease of herbicide application. Six species comprised the subplots, and 9 herbicide treatments and one untreated control were the mainplot effects. Planted rows were 1.2 m (4 feet) apart, and trees were planted 0.6 m (2 feet) apart within the rows. Data were analyzed, however, on a species-by-species basis, ignoring the splitplot nature of the design and treating the plantation as a complete randomized block design.

Because soil moisture was extremely low at the time of planting, a standard sprinkler irrigation system was installed on the site. Approximately 2.5 cm (1 inch) of water was applied after planting and before treatment with herbicides.

Table 3—*Weeds present on test site, 3 months after application of weed control*

Common name	Latin name	Weed status
Tumble pigweed	*Amaranthus albus* L.	d,h,s
Common ragweed	*Ambrosia artemisiifolia* L.	d
Yellow rocket	*Barbarea vulgaris* R. Br.	d,s
Shepherd's-purse	*Capsella bursa-pastoris* (L.) Medikus	d,h,s
Common lamb's-quarters	*Chenopodium album* L.	d
Horseweed	*Conyza canadensis* (L.) Cronq.	d
Wild carrot	*Daucus carota* L.	d
Hairy crabgrass	*Digitaria sanguinalis* (L.) Scop.	d,h,s
Quackgrass	*Elytrigia repens* (L.) Nevski	d
Stinkgrass	*Eragrostis cilianensis* (All.) Lutati.	d
Rough fleabane	*Erigeron strigosus* Muhl.	d
Wild strawberry	*Fragaria virginiana* Duchesne	d
Tall lettuce	*Lactuca canadensis* L.	d
Field pepperweed	*Lepidium campestre* (L.) R. Br.	d
Black medic	*Medicago lupulina* L.	d,s
Common yellow woodsorrel	*Oxalis stricta* L.	d
Witchgrass	*Panicum capillare* L.	d,h,s
Pokeweed	*Phytolacca americana* L.	d
Buckhorn plantain	*Plantago lanceolata* L.	d,h
Purslane	*Portulaca oleracea* L.	d,h,s
Silver cinquefoil	*Potentilla argentea* L.	d,h
Red sorrel	*Rumex acetosella* L.	d,h,s
Curley dock	*Rumex crispus* L.	d
Yellow foxtail	*Setaria pumila* (Poiret) Roemer & Schultes	d
White cockle	*Silene alba* (Miller) Krause	d
Common chickweed	*Stellaria media* (L.) Villars	d
Red clover	*Trifolium pratense* L.	d
Common mullein	*Verbascum thapsus* L.	d

d = Weeds present in diphenamid treatments, h = weeds present in hexazinone treatments, and s = weeds present in simazine treatments.

Treatment and Analysis

Herbicides were sprayed over the seedlings the day after planting using a tractor-mounted boom-type sprayer. The boom was arranged to spray a 1.2-m (4-foot) strip through two 8006 flat fan nozzles at 40 psi. Tractor speed was varied to achieve the recommended application rates listed in table 1. No rain fell for 24 hours after herbicide treatment, so irrigation was resumed on June 9, 1985, and continued as necessary so that moisture did not limit the growth or survival of the seedlings. When rainfall became normal by mid-July, irrigation was discontinued.

The effect of the herbicides on the weeds and trees was monitored throughout the growing season, and final measurements were made on September 3, 1985. The total height of all seedlings was measured, and plot means were computed. Plot survival was determined and expressed in percent. Survival data were transformed using the arc-sine date transformation (6) to yield a variable that was normally distributed. A summary of the weed population in each treatment was also made. An analysis of variance in total height and transformed survival was performed. As previously mentioned, the split-plot nature of the plantation design was ignored and data analyses were conducted independently for each species.

Results and Discussion

Weed control effectiveness. Weed control on the test site was good for all herbicide treatments during the first month of the test. During the second month, differences became apparent, and by the third month it was possible to identify the acceptable and unacceptable treatments. Diphenamid, when applied under these conditions, gave completely unacceptable weed control. Twenty-eight species of weeds were identified in the untreated control plots 3 months after treatment. These same weeds were found, growing vigorously, in all diphenamid-treated plots as well. In contrast, only 8 of these species were found in significant levels in the hexazinoneand simazine-treated plots (table 3).

The vigor of the weed growth varied among the treatment levels of hexazinone and simazine. Complete weed control (100%) was achieved at the highest level of hexazinone. Acceptable weed control (about 80%) was achieved at the medium level of hexazinone and the highest level of simazine. Approximately 50% weed control was achieved with the lowest level of hexazinone and the medium level of simazine. The lowest level of simazine gave unacceptable weed control.

Effects on height growth. Significant differences among treatments for height were only found for red oak (table 4). No treatments were associated with significantly taller or shorter seedling height than the control,

Table 4—*Mean plot heights of plots of seedlings under nine herbicide and one control treatments, 3 months after planting*

	Average height (mm)					
Herbicide treatment	European larch	Red oak	Tag alder	Ailanthus	Black locust	Kellogg hybrid pine
Diphenamid						
Low	224	306	454	401	700	117
Medium	205	210	414	378	643	127
High	263	332	398	252	728	108
Hexazinone						
Low	190	216	536	226	598	113
Medium	208	241	446	290	623	126
High	160	244	442	462	Dead*	109
Simazine						
Low	251	313	368	405	781	138
Medium	258	246	504	297	654	127
High	176	253	503	334	624	127
Control	228	280	480	271	658	138
LSD[a]	NS	80	NS	NS	NS	NS

[a]LSD computed for the comparison of 2 means with alpha = 0.05.
NS = Differences not significantly different at alpha = 0.1.
*All black locust were killed under this herbicide treatment.

however, and no significant trends existed among levels of any one herbicide. The herbicides neither increased nor decreased the height growth of treated seedlings in comparison to untreated seedlings. This indicates not only that surviving seedlings were not affected by the presence of herbicide in the soil but also that there was no positive benefit from the removal of weed competition from the site during the first year after planting.

This second result is unexpected since many researchers have concluded just the opposite (4). The lack of improvement in height growth under low weed competition may be due to one or a combination of three factors: 1) Growth was only measured for 3 months, and significant differences may take longer to develop. 2) Water competition from weeds is often cited as one cause for reduced crop growth, but irrigation kept water nonlimiting throughout most of this test. 3) The nutrient status of the test site was poor and may have been growth-limiting under all treatments.

Effects on survival. Herbicide treatment had no significant effect on the survival of Kellogg hybrid pine, tag alder, and red oak, but mortality of European larch, ailanthus, and black locust treated with all levels of hexazinone was significantly greater than the control (table 5). Even though hexazinone did not significantly reduce the survival of red oak below control levels, the leaf margins of the oak seedlings were burned, indicating mild herbicide damage. Previous reports indicate that red oak and other oaks are killed by hexazinone (2), but this mortality may be at concentrations higher than those tested here. Until more data are available, hexazinone should not be used on red oak.

Hexazinone has previously been shown to be safe for use over Scotch pine (*Pinus sylvestris* L.) and red pine (*P. resinosa* Ait.) in unpublished studies at Michigan State University, relatively safe for use on ponderosa pine (*P. ponderosa (*Engelm.) Shaw) and Douglas-fir (*Pseudotsuga*

Table 5—*Summary of mean plot survival over 6 blocks of 6 species under 9 herbicide and one control treatments, 3 months after planting*

Herbicide treatment	Percent survival (arc-sine transform of survival)					
	European larch	Red oak	Tag alder	Ailanthus	Black locust	Kellogg hybrid pine
Diphenamid						
Low	100 (1.6)	88 (1.2)	92 (1.3)	88 (1.2)	62 (0.8)	100 (1.6)
Medium	79 (1.1)	79 (1.1)	83 (1.2)	88 (1.2)	71 (1.0)	100 (1.6)
High	83 (1.2)	96 (1.4)	79 (1.1)	92 (1.3)	83 (1.2)	100 (1.6)
Hexazinone						
Low	12 (0.1)	75 (1.0)	79 (1.1)	54 (0.7)	12 (0.1)	96 (1.4)
Medium	12 (0.1)	71 (1.0)	96 (1.4)	67 (0.8)	12 (0.1)	100 (1.6)
High	12 (0.1)	87 (1.2)	75 (1.0)	21 (0.3)	0 (0.0)	96 (1.4)
Simazine						
Low	92 (1.3)	79 (1.1)	88 (1.2)	96 (1.4)	67 (0.8)	100 (1.6)
Medium	88 (1.2)	79 (1.1)	79 (1.1)	96 (1.4)	71 (1.0)	100 (1.6)
High	88 (1.2)	92 (1.3)	92 (1.3)	96 (1.4)	67 (0.8)	96 (1.4)
Control	92 (1.3)	96 (1.4)	92 (1.3)	92 (1.3)	79 (1.1)	96 (1.4)
LSD[a]	— (0.4)	NS	NS	— (0.5)	— (0.5)	NS

[a]LSD computed for the comparison of 2 means with alpha = 0.05.
NS = Differences not significantly different at alpha = 0.1.

menziesii [Mirb.] Franco) by Stewart (7), and on several southern pines (1). This list may now be expanded to include Kellogg hybrid pine and tag alder on coarse soils at these rates.

Simazine and diphenamid had no effect on survival at the rates tested.

Conclusions

Because height growth was unaffected by herbicide treatment in this study, treatment effectiveness was determined by seedling survival and quality of weed control. Even though all diphenamid treatments and the lowest level of simazine did not adversely affect the seedlings, they produced unacceptable weed control and therefore cannot be recommended. Hexazinone gave excellent weed control but was nontoxic only to tag alder and to Kellogg hybrid pine at the levels tested; it is of value, nonetheless, for release spraying in established plantations of other species. Simazine at 4 or 6 pounds of active ingredient per acre gave good weed control, was not toxic to any of the species (European larch, Kellogg hybrid pine, red oak, tag alder, black locust, and ailanthus), and therefore was the only acceptable, general-purpose herbicide tested under these conditions.

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Seed Collection From Loblolly Pine Cones After Tree Shaking

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*Seed collection from loblolly pines (*Pinus taeda *L.) is compared in bagged cones from trees shaken mechanically or by the turbulence from a helicopter in flight. Seeds were collected from full unopened cones and then collected in bagged cones after a shaking treatment. Timing of the helicopter flight seriously affected the number of seeds loosened by the shaking.* Tree Planters' Notes 39(2):19-21; 1988.

Over half of the southern pine seedlings produced in 1984 were from seed-orchard seed. Demand for seed-orchard stock will continue to increase for the next 10 years, until all seedlings are grown from known parentage. These are expensive sources: a recent survey of southern nurseries found that seed cost was the largest single expense of seedling production (3).

If production efficiency of 115,000 pounds of seed collected could be increased by only 10%, another 92 million seedlings could be produced, enough to plant an additional 164,000 acres.

Lantz (1) projected potential losses of $6,000 per acre from mistakes made in management of seed orchards and the collection and processing of cones. In this example, seed-orchard seeds were valued at $300 per pound, and about half of the losses were during cone collection.

The collection of loblolly pine seeds is complicated by the demand for larger annual harvests of seeds and by the increasing height of parent trees in seed orchards. Cones on the larger trees are now approaching or exceeding the reach of pickers on mechanical buckets and platforms. The net retrieval system (2) is an alternative to hand picking. However, this system relies on seeds falling onto the net. A tree-shaking apparatus is one means of increasing the number of seeds falling onto the net from the cones.

This report evaluates seed collection from loblolly pines (*Pinus taeda* L.) using four mechanical tree-shakers and helicopter turbulence to loosen seed.

Materials And Methods

Four mechanical tree-shakers were brought to Arrowhead Seed Orchard, Georgia Forestry Commission, during November 1984. The shakers were manufactured by Food Machinery Corp. (FMC), Kilby, Westech, and Orchard Machinery Corp. (OMC).

Before trees were shaken, paper bags were placed over five cones of one ramet (i.e., individual tree) of three clones. Enough ramets were selected and bagged to allow a control treatment (no shaking) and one treatment representing each of the four tree-shakers. The control cones were cut from the parent trees and taken to the laboratory where their seeds were extracted for a total seed count. After each tree had been shaken, the bagged cones were removed and taken to the laboratory, and the loose seeds in each bag were counted. Each treatment was then statistically compared with other treatments for significance.

Helicopter turbulence trials were conducted at the USDA Forest Service Francis Marion Seed Orchard in South Carolina. Cones were picked in October 1985 to determine the number of seeds in full, unopened cones (controls). In December 1985, the helicopter flew over selected clones that had cones bagged for collecting seed dispersals. Other trees in the same clones were shaken mechanically with a Savage 4200 tree shaker mounted on a tractor with a 3-point hitch. Seeds were collected from bagged cones immediately before and after tree-shaking for both aerial and ground treatments. A minimum of 10 cones from 2 ramets of each of 10 clones was collected (a total of 200 cones each treatment). The same clones were represented in each treatment.

Results

None of the mechanical shakers showed a clear advantage over the others for shaking seeds from cones. Although each shaker clearly released seeds from cones, a standard t-test showed only one significant difference. The FMC showed a significant difference (0.05 level) over the OMC in the number of seeds shaken from cones. All shakers left seeds in the cones: the percentage of seeds ranged from 30 to 60%.

When the number of seeds remaining in cones before and after both ground-shaking and aerial-shaking by a helicopter are compared (table 1)--76 percent of seeds remaining in cones (24 percent shaken out) after aerial-shaking and 57 percent of seeds remaining (43 percent shaken out) after ground tree-shaking–the values are somewhat misleading. The tree-shaker (mechanical tree planter) was owned and operated by the seed orchard unit and was available on demand. Therefore, the trees were shaken when cones were open during opportune weather conditions (temperature and humidity). However, the helicopter was scheduled in advance and actually flew over the trees when cones were not completely open because of unfavorable temperature and humidity.

Table 1—*Collection of seeds from cones of South Carolina Piedmont loblolly pines at Francis Marion Seed Orchard after shaking treatment*

Mechanical shake		Helicopter wash shake	
Before	After	Before	After
Total number of seeds remaining in 10 cones of each sample tree (ramet)			
1,259	737	1,323	931
1,163	1,085	1,117	1,083
812	663	515	1,130
1,681	229	1,469	478
1,287	976	1,786	966
787	906	946	931
1,319	735	1,188	NA
1,344	200	1,252	627
1,790	1,100	1,570	1,399
1,704	1,293	1,713	1,675
871	812	1,208	1,279
1,423	690	1,207	1,324
1,453	1,435	299	NA
1,243	924	1,309	1,600
1,655	243	1,505	735
1,478	295	1,513	959
1,232	500	1,221	1,137
1,231	1,001	1,233	932
1,012	154	1,398	338
1,243	180	1,291	192
Average number of seeds per tree (10 cones)			
1,249	711	1,253	984
Percentage of seeds remaining			
100	57	100	76

Values for the two shaking treatments on the same line represent cones collected from different trees (i.e., ramets) of the same clone. Cones for before values were harvested on October 28, 1985, before any of them had opened; bagged cones for after values were harvested immediately after the shaking treatments on December 11, 1985. NA = not available.

Conclusions and Recommendations

Comparison tests of tree shakers showed no clearly superior machine to disperse seeds from cones. Variable effects that must be considered for local application include the mechanical action of forces stressing the trees resulting from mechanical shaking; vibrations affecting terminal shoots, limbs, and crowns; and cost of the equipment.

Shaking from the ground was better than helicopter-shaking, but it is recommended that additional helicopter aerial-shaking be tried in order to enhance seed dispersal from pine cones. This will require close cooperation between orchard managers and helicopter crews to use the equipment during opportune weather conditions for open cones.

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Principles of Fungicide Usage in Container Tree Seedling Nurseries

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Fungicides are commonly used to control a wide range of diseases in container nurseries that produce conifer seedlings. These chemicals should be used only in conjunction with other practices of disease control. Proper use of chemical fungicides including types and amounts and timing of applications are discussed. Tree Planters' Notes 39(2) : 22-25; 1988.

Several pathogenic fungi cause greater amounts of disease in greenhouses than in bareroot nurseries because greenhouse conditions are so conducive to fungal growth, sporulation, and development. The artificial growing media often used in container operations either lack or have reduced populations of natural biological control organisms such as other fungi and certain bacteria and actinomycetes (4).

The conducive environmental conditions and lack of natural biological controls have usually resulted in widespread use of and dependency on chemical fungicides to reduce disease losses (5). Unfortunately, many growers use chemical fungicides rather indiscriminately whether or not a disease is present. Such actions are costly and often detrimental because of effects on nontarget organisms and increased possibility of development of resistance to fungicides by pathogenic fungi (7).

The Importance of Proper Diagnosis

Fungicides should generally not be used routinely in the absence of disease (14, 15). A possible exception is to control expected and recurring diseases such as damping-off during seed germination and seedling establishment. In such cases, fungicides are often applied shortly after sowing. However, fungicides should not be applied after the period of damping-off susceptibility (when young seedling stems have lignified) unless a specific disease has been identified.

A very important aspect of proper fungicide usage is diagnosis and identification of pathogens responsible for disease symptoms. Many of the newer fungicides are specific for particular species or genera of fungi rather than being appropriate against widely varying groups of fungi (1, 5, 8). For example, chemicals such as Aliette, carbanolate (Banol), and metalaxyl (Subdue) are only effective in controlling water mold fungi (6, 16). Water molds are a group of fungi (oomycetes) that include important plant pathogens such as *Pythium* and *Phythophthora*. These fungi differ chemically, morphologically, and evolutionarily from most other fungi. Use of fungicides specifically designed for water mold fungi to control other fungal pathogens will be largely ineffective. Such a practice may also be detrimental because it can a) eliminate resident populations of nonpathogenic water mold fungi, some of which may be competitors of pathogens (for example, saprophytic *Pythium* spp. compete against pathogenic *Pythium* spp.) and b) place unnecessary selection pressure on resident populations of water molds so that resistant individuals may proliferate in environments of high fungicide concentrations.

In another example, the selective fungicide PCNB (pentachloronitrobenzene) is very effective in controlling damping-off caused by Rhizoctonia but has no efficacy against other common damping-off fungi such as Pythium and Fusarium (16). In addition, some fungicides formulated to be effective against several different groups of fungi, such as carbanolate, have other problems, such as poor solubility in water, resulting in inadequate coverage of plant tissues (16).

Proper Timing of Application and Dosage of Fungicides

Many commonly used fungicides are protectants (15); those few that have therapeutic value are somewhat systemic and their ability to kill pathogenic fungi within host tissue is limited (8). Many fungicides inhibit spore germination or suppress sporulation of pathogenic fungi. Therefore, they should be applied when and where they can be most effective.

Growers should also remember that seedlings at different stages of development show variable susceptibilities to infection and only apply fungicides when host tissues are likely to become infected. For example, to control blight caused by *Botrytis cinerea* Pers. ex Fr., fungicides should be applied only after the seedling canopy closes and basal needles have become senescent, since these needles are the major site of infection by this pathogen (10). Applying fungicides directed at Botrytis before this stage of host development is wasteful and may even be detrimental because of potential fungicide resistance developing in the pathogen (7).

Preliminary evidence indicates that infection by Botrytis spores only occurs for a short time and most subsequent spread of the pathogen within greenhouses is vegetative (Sutherland, personal communication). Therefore, fungicides should be applied only during this short period of susceptibility. Research is currently underway to identify this period of susceptibility so that chemical control can be more effective.

Another disease in which proper fungicide timing and dosage are critical is postemergence damping-off. Seedlings are susceptible to this disease for only a short period of time after emergence. After stem tissues begin to lignify, seedlings are generally no longer susceptible to infection (17). Fungicides should only be applied if a damping-off problem is anticipated, such as with seedlots showing chronically poor vigor or problems of poor germination, and with highly contaminated seed. It is also important that fungicides not be applied past the period of host susceptibility to damping-off.

Application methods. Fungicides should be applied only to the portion of seedlings where the pathogen is active (5, 14). Foliage pathogens may be fairly easy to control with fungicides because the chemicals can be delivered to the site of infection with little difficulty. However, for root pathogens, it is much harder to get the fungicide to the site of pathogen activity (13). For example, attempts to control *Fusarium* root disease by drenching with fungicides have usually been ineffective (11, 12). This maybe because of inadequate fungicide concentrations at the site of pathogen activity in the roots of container seedlings.

Application rates. Fungicides should be applied at the lowest possible dosages that will effectively control the disease (15). Pesticide label rates have been developed to adequately control the target pest if applied properly. Excessive applications of fungicides are often detrimental because they often place selection pressures on pathogens to develop resistance (7). Because of their rapid reproduction rates and abundant propagule production, fungi can readily mutate to become resistant to fungicides.

New genetic strains of fungi often proliferate in an environment of high pesticide concentrations (7, 10). This behavior is especially common in response to some of the newer chemicals, which are more specific in their mode of action; one or two small mutations may be sufficient for an organism to develop resistance to these chemicals (8). Excessive fungicide applications can also kill beneficial organisms that may help keep pathogen populations in check. If fungicide concentrations continue at high levels, biological balances are disrupted and usually cannot be restored until these chemicals are no longer used.

Effects of Fungicide Use on Beneficial Microorganisms

The primary goal of fungicide usage should not necessarily be to kill organisms, but rather to reestablish a "biological balance" by reducing populations of pathogens and/or promoting proliferation of beneficial competitors (3, 4). For example, if a container-growing medium is fumigated with a general biocide such as methyl bromide or completely sterilized at high temperatures (autoclaved or microwaved), all organisms are killed (3). A "biological vacuum" is thus established, and the first organisms reinvading the medium often proliferate in the absence of competition. If the primary reinvading organism is a pathogen, such as *Fusarium* introduced on seed, much more disease will likely result than if the medium had never been treated.

In contrast, a process developed at the University of California (2) uses aerated steam to treat growing media to selectively kill pathogens. Steam treatment raises the temperature of a medium to approximately 50 °C, which is sufficient to kill most pathogens (including those that form resting structures such as chlamydospores and sclerotia) but does not harm certain sporeforming bacteria (primarily *Bacillus* spp. and some actinomycetes) that are important competitors and antagonists of pathogenic fungi. This steamtreated medium therefore, becomes "pathogen suppressive"; that is, if a pathogen is introduced into it, the organism cannot proliferate because of the competitive and antagonistic qualities of the current residents.

Another example of nonchemical disease control is maintaining or enhancing pathogen suppressiveness of a growing medium by amending it with composted tree bark (9). Such amendments enhance proliferation of certain bacteria and fungi by altering the chemical composition of the medium. In sterilized media, pathogens are usually suppressed at the expense of competitors and antagonists. However, if a biological balance or suppressive state is present, introducing chemical fungicides into the system will usually alter this balance, often to the advantage of pathogens.

Conclusions and Recommendations

The following guidelines can help growers in the proper use of fungicides to control diseases of containerized seedlings:

1. The proper fungicide should be used to control the proper pathogen; therefore, accurate diagnosis of the problem is essential.
2. Fungicides should be applied at the lowest possible dosage that will achieve disease control; application rates should never exceed label rates.
3. Use only fungicides that are registered for specific diseases on specific hosts.
4. Fungicides should be applied at the proper time and to the proper part of the seedling to control specific pathogens.
5. Fungicides should be used prudently and only when necessary to control diseases.
6. Fungicides should be used only when other practices of disease control are inadequate. These other practices include sanitation before and during the crop cycle and controlling the growing environment to render pathogens ineffective or hosts less susceptible to infection.

Fungicides may not adequately control a disease for the following reasons:

1. The disease may not be caused by a pathogenic fungus, but may be due to abiotic factors, insect damage, or other causes.
2. Resident pathogen populations may have acquired resistance to chemicals used.
3. There may be too much pathogen inoculum present. Consider problems of sanitation, seed contamination, and pathogen reservoirs such as weeds in and near greenhouses.
4. The fungicide used is effective, but does not reach the

site of infection by the pathogen.

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Fungicide Trials for Control of Phomopsis Canker of Douglas-Fir at a Northern California Nursery

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Based on in vitro *evaluation of sixteen fungicides, five were field-tested for efficacy against phomopsis canker of 2 + 0 Douglas-fir (*Pseudotsuga menziesii *(Mirb.) Franco). All gave significantly better control than no treatment. Benomyl, the fungicide registered for phomopsis control, was more efficacious than mancozeb and imazalil but was not as effective as diniconazole or chlorothalonil.* Tree Planters' Notes 39(2):26-29; 1988.

Phomopsis canker of 2+0 Douglas-fir, caused by *Phomopsis occulta*, usually results in scattered and infrequent losses at Humboldt Nursery (USDA Forest Service) in coastal northern California. About 5% of the crop is lost each year. However, incidence of the disease has increased the last few growing seasons, Benomyl is registered and used for control of *Phomopsis juniperovora*-caused diseases (1-3), but the effectiveness of the fungicide against *P. occulta* had not been previously tested. Humboldt Nursery currently uses benomyl, but the efficacy of the treatment has been questionable.

The increase in disease, along with the cost of benomyl and recommended frequency of application, caused the Nursery to request an evaluation of alternative fungicide treatments. The objective was to evaluate alternative fungicides for control of Phomopsis canker of Douglas-fir at Humboldt Nursery, through *in vitro* laboratory screening and field trials.

Methods

Laboratory screening. An isolate of *P. occulta* from 2+0 Douglas-fir seedlings at Humboldt Nursery was used. The isolate was morphologically identical to other Douglas-fir isolates and to isolates obtained from western hemlock.

Sixteen fungicides were initially selected (table 1) to determine their effect on spore germination. The fungicides were recommended and supplied by Dr. A.H. McCain, extension plant pathologist, University of California at Berkeley. Three concentrations (1, 10, and 100 ppm; active ingredient) of each fungicide were incorporated into 2% water agar (2 g agar/100 ml water). Spores were obtained by adding 10 ml of sterile water to each sporulating culture and brushing gently with a brush to dislodge spores. One milliliter of the spore suspension was placed onto the surface of each plate containing 2% water agar and incorporated fungicide. Four replications were made for each fungicide concentration and for a control (2% water agar without fungicide). After 24 hours' incubation, the percentage of germination was determined for each treatment. Germ tube development was followed over an 11-day period.

Table 1—*Fungicides evaluated* in vitro *for control of Phomopsis canker of 2+ 0 Douglas-fir*

Common name	Trade name
Benodanil	BAS 3170F 50W
Benomyl	Benlate
Captan	Captan 50W
Chlorothalonil	Bravo W-75
Chlorothalonil	Bravo 500
Diniconazole	Spotless (Chevron 779 12.5% W)
Dithianon	Delan 75 WP
Fenarimol	Rubigan 50W
Imazalil	Fungaflor 20% EC
Iprodione	Chipco 26019
Mancozeb	Dithane M 45
Penconazole	Topas (CGA 71818 10W)
Prochloraz Mn complex	Sportak 50W
Triadimefon	Bayleton 50WP
Tri-basic copper sulfate	Tri-Basic
Vinclozolin	Ornalin 50W

The seven fungicides that were most effective in inhibiting or reducing germination compared to the control were selected to determine their effect on mycelial growth. Three concentrations (1, 10, and 100 ppm active ingredient) of each were incorporated into potato dextrose agar (PDA). A 0.5-mm plug of mycelium of *P. occulta* was removed from the perimeter of an actively growing colony of

PDA and placed on the fungicide-amended PDA in petri plate. Four replications were made for each fungicide concentration and for a control (PDA without fungicide). Radial growth of mycelium from each plug was measured after 3 days' incubation.

Field trials. Five of the most effective fungicides from the laboratory trial were tested in field trials in 1985 and again in 1986. A randomized complete block design with six treatments—control; benomyl at 1 lb product/ acre; imazalil at 20 ounces product/acre; diniconazole at 0.2 lb product/acre; chlorothalonil (Bravo 500) at 5 pints product/ acre; and mancozeb at 2 lbs product/acre—was used. The six treatments were replicated 10 times down a bed of 2+0 Douglas-fir in 1985, and replicated 8 times in 1986. Each replicate covered 24 feet of bed (six 4 by 4 ft plots), with each treatment assigned randomly in each replicate.

The 1985 trial was initiated in June. Fungicide treatments continued at monthly intervals through September (four applications). In 1986, monthly fungicide treatments began in May and continued through August (four applications). Efficacy of treatments was determined by counting cankered seedlings monthly. After the final count, the total number of seedlings in each plot was counted, and percentage of seedlings cankered in each treatment determined.

Results and Discussion

Laboratory screening. Spore germination percentages are presented in table 2. Spores with emerging germ tubes after 24 hours' incubation were considered germinated. With some treatments (imazalil, prochloraz, diniconazole, penconazole and benomyl in particular), the germ tubes had limited development or became distorted.

Results of the effect of 7 fungicides on mycelial growth

Table 2—*Germination percentage of* Phomopsis occulta *spores after 24 hours on fungicide-amended media*

Fungicide	Percent germination at 3 concentrations		
	1 ppm	10 ppm	100 ppm
Chlorothalonil (Bravo 500)	0	0	0
Chlorothalonil (Bravo W-75)	71	0	0
Imazalil	41*	43*	0
Mancoxzeb	94	29	0
Captan	92	89	0
Dithianon	84	87	0
Prochloraz	80	62*	31*
Diniconazole	71	48*	28*
Penconazole	87*	89*	67*
Benomyl	95	88*	88*
Benodanil	82	80	27*
Tribasic copper sulfate	94	95	84*
Fenarimol	90	88	86*
Iprodione	91	90	89
Vinclozolin	92	91	88
Triadimefon	95	95	93

Control value = 98% germination.
* Germ tube inhibition or distortion.

Table 3—*Average radial growth of* Phomopsis occulta *after 3 days on fungicide-amended potato dextrose agar*

Fungicide	Radial Growth (mm) at 3 concentrations		
	1 ppm	10 ppm	100 ppm
Benomyl	0	0	0
Imazalil	0	0	0
Prochloraz	0	0	0
Diniconazole	1.1*	0	0
Chlorothalonil (Bravo 500)	2.2	0	0
Chlorothalonil (Bravo W-75)	15.5	1.7	0
Mancozeb	24.0	2.7	0

*Average of four replications.

are presented in table 3. After 11 days, no growth had occurred on benomyl-amended PDA at 1, 10, and 100 ppm, on imazalil-amended and prochloraz-amended PDA at 10 and 100 ppm, and on diniconazole and the Bravo 500 formulation of chlorothalonil-amended media at 10 and 100 ppm.

To determine if the fungicides were fungitoxic or fungistatic, plugs where no mycelial growth had occurred into the fungicide-amended PDA were removed, placed on PDA, and examined after 7 days (table 4). Benomyl and imazalil were fungitoxic at all concentrations. Prochloraz and diniconazole were not fungitoxic at 1 ppm, but were at 10 and 100 ppm, with mycelial growth occurring after the plug was removed from the fungicide-amended media. Chlorothalonil was fungitoxic only at 100 ppm.

Field trials. Based on the laboratory assays, 5 fungicides were selected for field trials. Levels of disease incidence during the 1985 trial were not sufficient to compare treatments as cankered seedlings in plots ranged from less than 1% to about 3%.

Results of the 1986 trial are presented in table 5. All 5 fungicides gave significantly better control of phomopsis canker than no treatment. Benomyl was more efficacious than mancozeb or imazalil, but was not as effective as diniconazole or chlorathalonil.

Table 4—*Mycelial growth of* Phomopsis occulta *on potato dextrose agar after 11 days on fungicide-amended potato dextrose agar*

Fungicide	Mycelial growth at 3 concentrations		
	1 ppm	10 ppm	100 ppm
Benomyl	−	−	−
Imazalil	−	−	−
Prochloraz	+	−	−
Diniconazole	+	−	−
Chlorothalonil (Bravo 500)	+	+	−

+ = Growth, − = no growth.

Table 5—*Percentage of 2+0 Douglas-fir seedlings cankered as a result of* Phomopsis occulta *infection at the Humboldt Nursery*

Treatment	Percent cankered
Diniconazole	1.9 a
Chlorothalonil	2.1 a
Benomyl	4.0 b
Mancozeb	5.1 c
Imazalil	5.3 c
Control	9.1 d

Means followed by the same letter are not significantly different at the 1% level, according to Duncan's multiple range test. Means are the average number of seedlings cankered in eight replicate plots.

Conclusions

Benomyl, the fungicide registered for control for *Phomopsis* spp., was efficacious under the conditions for the study. The label for benomyl suggests treatment at 10- to 14-day intervals. Because we used 28- to 30-day intervals, the fungicide may be even more effective if used according to label recommendations.

Chlorothalonil and diniconazole were more effective than benomyl. Chlorothalonil is registered for use on conifers in nurseries and could be used (5 pints product/acre, applied at monthly intervals throughout the growing season) as a replacement for benomyl for control of phomopsis canker. Diniconazole, although not currently registered for use in nurseries in California, has some systemic properties and therefore may be more effective than chlorothalonil or benomyl in preventing secondary infections during rainy periods.

Although fungicide treatments for control of phomopsis canker were effective under the conditions of this trial, results should be interpreted with caution because of the low incidence of disease during the two seasons of field testing. Incidence of phomopsis canker in nontreated portions of the test bed in the 1986 trial was low (9.1%), with little variation among the 8 replications. During years more favorable for disease development, the relative efficacy of the fungicides evaluated in relation to each other may vary.

Most of the cankers during these trials had caused dieback of lateral tips, with only about 10% of these infections resulting in death of the seedlings or cull due to killing of terminals. This low level of disease severity, along with the low levels of overall disease in test beds and production beds, suggests that no fungicide treatment the past two growing seasons may have been more economical than treatment with preventive fungicides. Observations in 1986 suggested that disease levels may have been lower than in previous years because seedlings were not top-pruned, a practice that creates wounds for infection.

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Growth and Survival of Slash Pine Seedlings in a Florida Nursery

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*Growth and development of slash pine (*Pinus elliottii *Engelm.) seedlings were monitored. About 11.5% of the seedlings died: 10.8% due to disease, 0.4% due to insects, 0.2% due to weather, and 0.1 % due to mechanical factors. The cull rate at lifting was influenced by the frequency of top pruning (once versus twice) and seedling density.* Tree Planters' Notes 39(2):30-36; 1987.

Knowledge of normal seedling growth and survival enables nursery managers to promptly identify abnormalities in their nursery stock (15). Growth and survival studies of slash pine (*Pinus elliottii* Engelm. var. *elliottii*) nursery stock have been reported from Georgia (11) and Louisiana (10) but not Florida. Slash pine is the principal forest tree in Florida, with over 5 million acres of plantations under intensive management (12).

To obtain desirable seedling densities at lifting, nursery managers adjust their sowing rates according to results of laboratory germination tests as well as the expected losses between germination and lifting (usually 10 to 30%) based on years of experience (15). The objectives of this study were a) to monitor growth and development of slash pine seedlings and b) to determine the cause, impact, and seasonality of seedling losses in a northcentral Florida nursery.

I thank Edward L. Barnard, forest pathologist with the Florida Division of Forestry; Caulie Sears, who is now retired from the Andrews Nursery; and Sheridan K. Haack for cooperation and technical assistance in this study.

Methods

This study was conducted at the Andrews Nursery (Florida Division of Forestry) in Chiefland, FL, during 1982. This nursery is typical of other Florida nurseries on sandy sites. Some of the 1982 management practices relevant to this study were: 1) spring soil fumigation with MC-33 (67% methyl bromide and 33% chloropicrin) at 350 pounds per acre; 2) pre-sowing fertilization with 15-0-15 (N-P-K) at 300 pounds per acre followed by two top-dressing applications of ammonium nitrate and 22-22-11 (Su-K-Mg), each at 150 pounds per acre; 3) repeated applications of ferbam for control of fusiform rust; 4) overhead irrigation when needed; 5) herbicide applications of oxyfluorfen (Goal) at 4-week intervals from time of sowing through August; and 6) two top prunings, one in late August and one in late September.

Slash pine seeds from four seedlots were planted between 29 April and 3 May in eight seedbeds; hence, 1 May will be used as the average planting date. Four beds were mulched with hydromulch and the other four with pine straw.

Seedlings were sampled biweekly from May through mid-June and then monthly through October. To monitor seedling growth, 10 seedlings were randomly selected and removed from each of the eight seedbeds (but not from sample plots) on each sampling date. Seedlings were removed from the two outermost drills on either side of the bed, put into labeled bags, and refrigerated until examined. Top height, stem diameter at ground line, and root length were recorded for each seedling. Observations were made on timing of seed coat loss, primary and secondary needle appearance, branching, bark and terminal bud formation, lateral root development, and root colonization by mycorrhizal fungi.

Seedling survival was monitored in 40 plots (1 foot long by 4 feet wide) positioned across seedbeds and randomly located throughout the eight beds (five plots per bed). The plots were established immediately after sowing so that all seeds could be located. To enable individual seedling recognition, eight maps were made per plot, one corresponding to each of the eight seed drills per bed. The maps were drawn on 12-inch wooden garden labels, showing the location of each seed and eventual seedling. Dates of germination and mortality (if it occurred) were recorded for each seedling on the 320 maps. The probable cause of seedling death was determined on the basis of field and laboratory observations and tests.

The effects of top pruning on seedling cull rate were studied in the four beds with hydromulch. On 15 August, each seedling less than 15 cm tall was so designated on the appropriate map. All 20 plots in these four beds were top pruned in late August, and 10 of these were again top pruned in late September.

On 6 November, 27 weeks after sowing, all seedlings from each of three drills per plot were removed from the 20 plots. The drills were randomly selected within each plot; however, one drill was always an outside drill, while the other two were selected among the inner six drills. Seedlings from each drill were placed between two strips of masking tape in the same order that they had been growing. Similar measurements to those mentioned above as well as whether top pruning had occurred were recorded for each seedling.

Results and Discussion

Seedling Growth. Development of seedlings in the four seedlots was similar and thus the data were pooled. Within 2 weeks of sowing, over 70% of the seeds had germinated and taken root (table 1). Germination was nearly complete within 4 weeks of sowing. Similarly, Huberman (10) found that most seeds of southern pines germinated between 12 and 20 days after sowing.

Once a seedling was established, root growth occurred more rapidly than top growth (fig. 1). Rapid elongation of the primary root continued through mid-July, but elongation virtually stopped thereafter. Lateral roots were not present on any seedling collected 2 weeks after sowing, but they were found on nearly all (98%) seedlings within 4 weeks. Huberman (10) reported a similar pattern of root growth for slash pine seedlings. In other studies (15), root length was found to be influenced by soil texture and soil moisture. Hence, the long tap roots observed in this study may, in part, reflect the sandy soils at Andrews Nursery. Mycorrhizae were first observed on a few seedlings collected in July, while nearly all seedlings were well-colonized by September (table 1).

Seedling top growth followed a sigmoidal curve (fig. 1). Top growth was slow during the first 6 weeks after sowing, consisting mostly of elongation of the stem (epicotyl) and cotyledons, and emergence and elongation of the primary needles. Seed coats were still attached to most (82%) seedlings 2 weeks after sowing; however, within 4 weeks most seed coats were shed (table 1).

Table 1—*Seasonal occurrence of various growth characteristics of slash pine seedlings (80 per sampling date) planted 1 May and tested 2 to 10 weeks later*

Seedling growth characteristic	Percent of seedlings						
	2 wks (15 May)	4 wks (30 May)	6 wks (13 June)	11 wks (17 July)	15 wks (15 Aug.)	20 wks (18 Sept.)	24 wks (16 Oct.)
Germination	71	98	99	100	—	—	—
Mycorrhizae	0	0	0	23	59	92	100
Seed coat attached	82	13	8	2	1	1	1
Cotyledons expanded	18	97	99	100	—	—	—
Primary needles	0	94	98	99	100	—	—
Secondary needles	0	0	0	95	99	100	—
Woody stems	0	0	59	98	99	99	99
Branches	0	0	0	55	45	60	44
Terminal bud	0	0	0	0	0	0	15

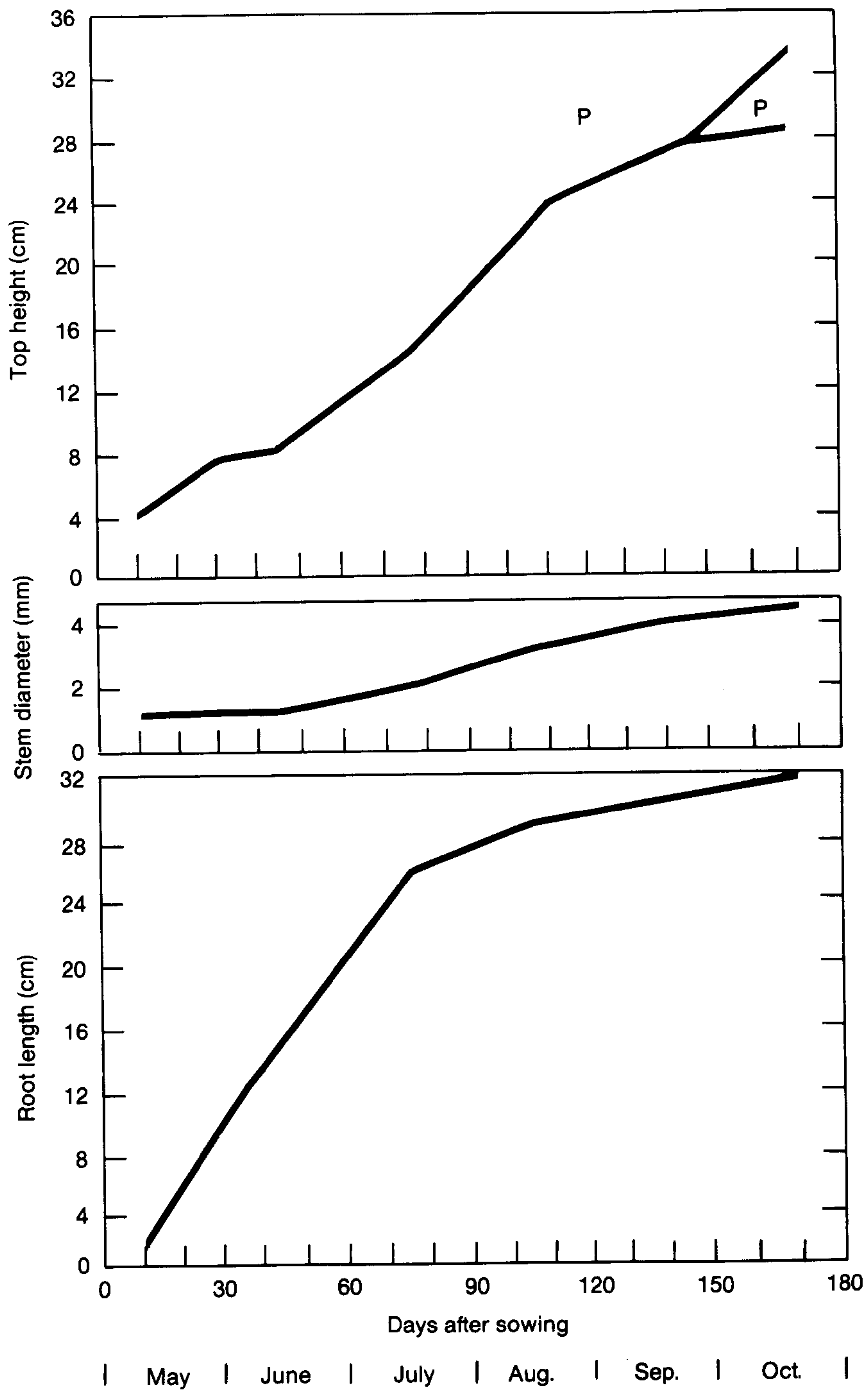

Figure 1—*Cumulative top, stem, and root growth of slash pine seedlings sown on 1 May. P = top pruning of all (August) or half (September) of the sample plots.*

Cotelydons were expanded (free of the seed coat) on 18% of the seedlings within 2 weeks of sowing and on nearly every seedling within 4 weeks (table 1). Primary needles appeared on almost every seedling within 4 weeks of sowing; secondary needles (needles in fascicles) appeared on most seedlings within 11 weeks of sowing (table 1).

Stem diameter increased very little during the first 6 weeks after sowing, but thereafter it increased rapidly (fig. 1). The lower stems of some seedlings changed from green and soft to reddish and woody within 6 weeks of sowing (table 1). Branches were first observed on seedlings collected in July, with about half the seedlings possessing branches on each sampling date thereafter (table 1).

Terminal buds were first present on seedlings collected in October (table 1). Of the 12 seedlings with terminal buds, 3 had been top pruned and the other 9 had not. The effects of top pruning on seedling height are shown in figure 1. In most respects, the patterns of early seedling growth recorded here were similar to those reported by Huberman and Rowan (10, 11). However, seedling growth after initial establishment appeared much faster in this study, probably reflecting the warmer temperatures of Florida.

Seedling Survival. Of the 6,865 seeds sown in the 40 plots, 77% successfully germinated and rooted (table 2). Average laboratory germination for these seedlots was 88%. Although not quantified, some of the 1,553 seeds classified as dead (table 2) could have died from pre-emergence damping off, failure to root, or other causes. Of the 5,312 seedlings that successfully rooted, 11.5% died by the last sampling date-i.e., 24 weeks after sowing (table 2); seedlings were lifted in late November. Such losses are similar to those (11 to 12%) reported recently by other southern nurseries (4). Six factors were identified as causing seedling mortality (table 2): two are diseases (post-emergence damping off and pitch canker), two are insects (cutworms and pine webworm), one is weather (rain-induced erosion), and one is mechanical (tire damage).

Of the seedlings that died, over 90% apparently succumbed to damping off (table 2); however, sun scald may have killed some. Losses to damping off occurred early in the growing season, with mortality appearing earlier (but not more severely) in beds mulched with hydromulch as compared with pine straw. In hydromulch plots, 71% of the 258 damped-off seedlings died prior to 30 May (4 weeks after sowing). In contrast, 78% of the 293 damped-off seedlings died after that date in plots with pine straw. Damping-off organisms may develop differently under these two mulches due to possible variations in microenvironments.

Identifiable losses to pitch canker occurred late in the growing season (table 2), or at least that is when diseased seedlings became evident-i.e., foliage turned from green to red. This fungal disease has been recognized only recently as a threat to nursery stock (1). Infected seedlings often occurred in groups, with each seedling having a resin-soaked stem canker near the ground line.

Insects were far less damaging than diseases when comparing total seedling losses-i.e., 3

Table 2—*Survival and mortality of slash pine seedlings*

Sampling date (wks after sowing)	Seeds or seedlings			Seeds or seedlings killed						
	Alive									
	Total	No./ft²	Dead	Seed death[1]	Damping off	Pitch canker	Cutworm	Webworm	Erosion by rain	Mechanical
Survival (No.)										
1 May (0)	6,865	43	0	0	0	0	0	0	0	0
15 May (2)	5,290	33	1,575	1,553	21	0	1	0	0	0
30 May (4)	5,058	32	1,807	0	224	0	8	0	0	0
13 June (6)	4,796	30	2,069	0	250	0	0	0	8	4
17 July (11)	4,739	30	2,126	0	56	0	0	0	1	0
15 Aug. (15)	4,722	30	2,143	0	0	7	0	9	0	1
18 Sep. (20)	4,703	29	2,162	0	0	17	0	2	0	0
16 Oct. (24)	4,702	29	2,193	0	0	1	0	0	0	0
Total				1,553	551	25	9	11	9	5
Mortality (%)										
Of all 6865 seeds				22.6	8.0	0.4	0.1	0.2	0.1	0.1
Of all 5312 seedlings					10.4	0.5	0.2	0.2	0.2	0.1
Of the 610 dead seedlings					90.3	4.0	1.5	1.8	1.5	0.9

[1]All seeds were considered viable at time of sowing.

versus 94%. Similar loss patterns have been reported (8). Early in the growing season, cutworms were responsible for the insect-related mortality (table 2). Cutworms, which feed mostly at night, are caterpillars of moths in the family Noctuidae. All cutworm-damaged seedlings were in the cotyledon stage. Characteristic damage is a seedling bitten through the stem near the ground line. Some cutworms were found just under the soil in close proximity to damaged seedlings during the daytime. Although losses were small in this study, cutworms are potentially very destructive (15).

Pine webworms were found defoliating seedlings late in the growing season (table 2). Pine webworms are larvae of moths in the family Pyralidae. Early larval stages mine needles when small, but later larval stages feed externally and form communal "frass nests" within the foliage. This insect can complete three generations per year in north Florida (9). The larvae observed in this study were probably members of the second generation, the offspring of moths that recently had completed development on pines in nearby stands.

Some seedling losses resulted from weather and mechanical factors (table 2). Twice, heavy rains eroded soil from around seedlings (in the outermost drills only), exposing roots to desiccation. Similarly, on two occasions during regular nursery operations, a tractor tire hit and dislodged soil from the side of the bed. This resulted in roots of a few seedlings being exposed to the sun, which eventually resulted in their death.

Two weeks after sowing, at which time 98% of the seeds had germinated, the initial seedling density was 33 seedlings per square foot (43 seeds per square foot sown) (table 2). Although the density desired at lifting was 27 seedlings, 29 seedlings per square foot occurred. This density is close to the range (25 to 28) recommended for slash pine (5).

Effects of Top Pruning. Seedlings are top-pruned to improve the shoot-to-root ratio, produce seedlings of more uniform height, reduce the number of cull seedlings, and improve field survival (7). In this study, the effects of top pruning once (392 seedlings) versus twice (427 seedlings) on seedling cull rate were determined using Wakeley's (15) slash pine standards for minimum height (15 cm), maximum height (33 cm), and minimum stem diameter (3.2 mm).

Between 15 August and 6 November, the number of seedlings under 15 cm in height decreased from 4.8 to 1.5% in once-pruned plots (69% reduction), and from 4.7 to 0.2% in twice-pruned plots (96% reduction). These data indicate that more seedlings were released from competition when top pruning occurs twice rather than once.

Seedlings much over 33 cm tall are often culled because they are not easily handled during mechanical planting and they tend to be easily wind whipped and die of desiccation after outplanting (15, 17). In this study, none of the twice-pruned seedlings was more than 33 cm tall. However, 77% of the once-pruned seedlings were oversized. These data suggest that slash pine seedlings will usually require two top prunings under Florida conditions.

Seedling stem diameters 27 weeks after sowing (2 to 3 weeks prior to lifting) ranged from 0.8 to 8.2 mm. Average stem diameter was larger for seedlings from outside drills (4.6 mm, N = 268) than from interior drills (4.1 mm, N = 551). Hence, the stemdiameter values presented in figure 2 may be slightly overestimated because seedlings in only the outer drills were selected. Using Wakeley's 3.2 mm as the minimum acceptable stem diameter for slash pine seedlings, cull rates were similar (17% between once-pruned and twice-pruned plots).

Cull rate, based on minimum stem diameter, was affected by

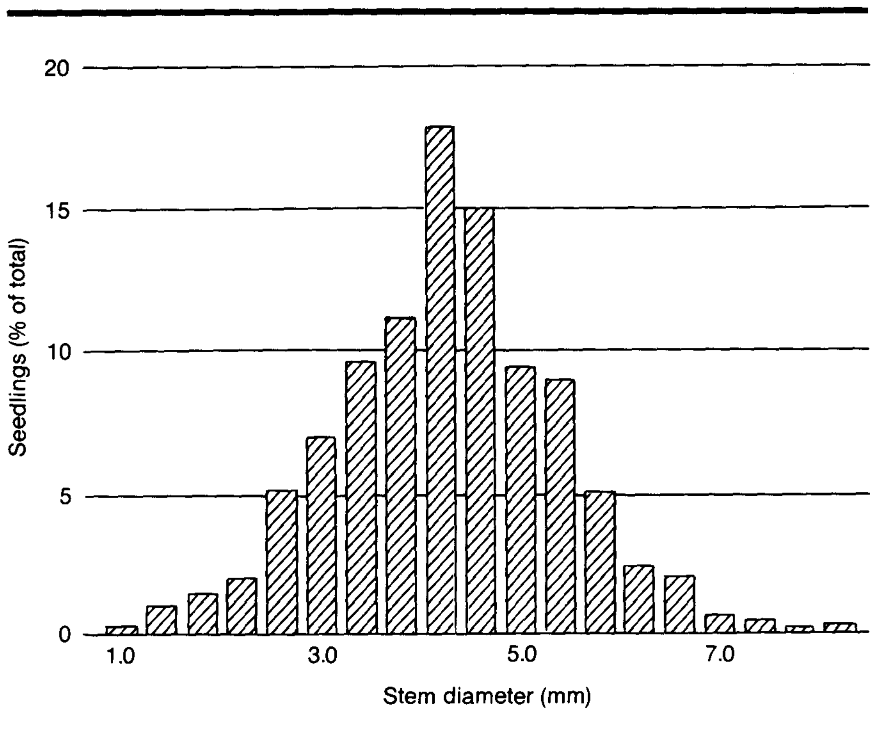

Figure 2—*Distribution of slash pine seedlings by 4-mm stem diameter classes when lifted in November, 27 weeks after sowing.*

seedling density—i.e., the number of seedlings per 1-foot drill. In this study, cull rate was positively correlated (r^2 = 0.6) with seedling density. The highest number of culls was 14 when 29 seedlings grew in a single 1-foot drill. There were usually 1 to 2 culls when 12 to 14 seedlings were growing per 1-foot drill.

Hence, besides selecting the proper initial sowing rate, spacing the seed evenly within the drills is also very important in regulating seedling quality, and thus their grade. In other studies, high seedling densities resulted in more low-grade (cull) seedlings (6, 13). This is an important consideration for southern pines because several studies have reported that seedling grade was directly related to eventual field performance (3, 6, 14, 16).

Several nursery practices at the Andrews Nursery have changed since 1982. These include: (1) planting in early April instead of late April, (2) mulching with chopped coastal Bermudagrass hay, wood chips, or bark chips instead of hydromulch or pine straw, (3) use of bay meb 6447 (Bayleton) rather than ferbam for fusiform rust control, and (4) root pruning. These new practices will most likely alter the seasonal patterns reported in this study. For example, earlier planting should shift many of the growth and mortality parameters forward in time; the new mulches could change the seedbed microenvironment, thereby altering patterns of germination and disease incidence; use of Bayleton may slow mycorrhizal colonization because it is known to inhibit their growth (2); and root pruning may reduce the rate of top growth as well as induce greater development of lateral roots (5).

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Vegetative Propagation of Yellow Birch From Stem Cuttings

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*Softwood cuttings from yellow birch (*Betula alleghaniensis *Britt.) trees of up to 38 years of age were rooted in a greenhouse under intermittent mist using commercial rooting compounds containing NAA or IBA. Rooting percent varied considerably among clones. Average rooting success over all treatments and conditions with forest-grown trees as the dominant source of cuttings was 23.5 and 17.7% in 1977 and 1978, respectively. Best rooting occurs during July and August, but plants rooted in early summer have the best chance of surviving through the winter in the nursery and being successfully field planted*. Tree Planters' Notes 39(2):37-42; 1988.

Yellow birch (*Betula alleghaniensis* Britt.) is a northern hardwood in considerable demand primarily for veneer and furniture manufacturing. Because of its high value, there has been some effort to study the genetics of yellow birch (2) and its response in plantations (5).

Though vegetative propagation has been tried with many southern broad-leafed tree species, it has not been extensively tested with yellow birch to perpetuate desirable phenotypes (7. Gabriel (4) has rooted yellow birch cutting from trees up to 80 years old, but less than 5% of all cuttings survived the winter and they died soon after budbreak.

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Among other birches, Hares (6) reported best rooting success with paper birch (*B. papyrifera* Marsh.) and European white birch (*B. pendula* Roth.) in late summer using 2000 ppm indolebuteric acid (IBA) in solution with a 5-second dip. Dosser and Hicks (3) found early spring was the optimal time for rooting cuttings from river birch (*Betula nigra* L.) and observed considerable tree-to-tree variation (clonal differences) in rooting.

Cesarini and Minamoto (1) rooted European white birch with 1% IBA and Hormodin 3 (0.8% IBA in talc). Vaclav (9) reviewed several techniques used to propagate European birches, including rooted cuttings, and noted good success and rapid rooting with softwood cuttings; hardwood cuttings by comparison took over 2 years to root. Pelham and Mason (8) also reported good success rooting cuttings from European white birch seedlings in an agar medium.

Recent advances in rooting of birches and the steady demand for high-quality yellow birch prompted studies to determine if rooting of yellow birch cuttings, and transfer to nursery transplant beds as an intermediate step to planting, could be achieved.

Materials and Methods

Preliminary trials with hardwood cuttings of yellow birch produced abundant callus but no roots; thus studies were pursued with softwood cuttings from seedlings grown in a greenhouse and in nursery beds and from forest-grown trees.

In the first studies, 2-year-old yellow birch seedlings were dug from nursery beds at the Vermont State Nursery in Essex Junction in January of 1976, potted, and placed in a heated greenhouse. The seedlings broke dormancy soon after transfer, and in April softwood cuttings were taken from both lateral and terminal shoots. Stem diameters of cuttings averaged about 0.1 inch and stem length ranged from 4 to 6 inches, depending on their position on the plant. Most cuttings had 2 leaves and 1 to 2 inches of stemwood below the lowest leaf. Each cutting was immediately dipped about 1/2 to 1 inch into a commercial rooting formulation and inserted about 2 inches into the rooting medium on a greenhouse bench.

Five different commercial rooting compounds were tested during 3 years of study: Hormodin 1, 2, and 3, Rootone F, and Strike.[a] The rooting medium was

Hormodin 1 = 0.1% indole-3-butyric acid; Hormodin 2 = 0.3% indole-3-butyric acid; Hormodin 3 = 0.8% indole-3-butyric acid; Rootone F = .067% 1-napthyleneacetic acid, .003% 2-methyl-1-napthyleneacetic acid, .013°/ 2-methyl-l-napthaleneacetamide, .057% indole-3-butyric acid with thiram fungicide; and Strike = 1-napthaleneacetic acid, plus captan fungicide (concentration not specified, presumed about 0.5%).

fine gravel passing a ¼-inch screen and spread 4 inches deep over 2 inches of coarse gravel on a greenhouse bench. Rooting bed temperature was maintained at about 70 °F by a heating coil placed approximately 3 inches into the fine gravel. Mist was used throughout the rooting period. It was initially controlled by a Mist-a-Matic apparatus, then later by an electric interval timer that misted for 5 seconds every 6 minutes. Natural daylight was extended to 18 hours for all phases of greenhouse treatment using fluorescent and incandescent lamps. These greenhouse and rooting bed conditions were used for cuttings from greenhouse and nursery-grown seedlings, and forest-grown trees.

Cuttings were examined for rooting once a week. At the first signs of rooting, cuttings were potted in 3-inch-square containers in a medium consisting of 6:3:2:1 ground peat/fine gravel/loam/sand by volume. Osmocote slow release fertilizer (18-6-12) was added at 1.2 g/pot. Cuttings were then placed on a mist bench for 5 to 10 days and watered at half the rate of the nonrooted cuttings. Plants were then transferred to a greenhouse bench and hand watered as necessary.

Cuttings that grew a root System that occupied the pot volume were transplanted into larger pots. Cuttings that developed new shoot growth were transplanted to an outdoor nursery bed under 30% shade provided by slat frames.

During the summers of 1976, 1977, and 1978 (June to September) cuttings were taken at various intervals from nursery seedlings and 34 naturally growing yellow birch trees up to 38 years of age from a wide geographic range in Vermont. Sampling intervals ranged from 7 to 10 days for many trees to only once or twice a season for some small trees, or trees at distant locations. Each collection time (for each tree) was defined as a batch.

Freshly cut shoots were placed in plastic bags with some water and transported in an ice chest to the greenhouse. Shoots were stored in a refrigerator overnight, or immediately retrimmed, dipped about 1 inch into rooting powder, and Inserted in the mist bench. An attempt was made to collect at least 10 cuttings per tree, but small greenhouse or nursery plants often yielded fewer then 10. Two or three cuttings were usually obtained from a new lateral or terminal shoot.

Data were analyzed for rooting percentages using the Duncan's multiple range test.

Results

1976 trials. During the 1976 growing season, 311 cuttings were taken from 18 different greenhouse, nursery, and natural-growing trees and treated with Strike or Hormodin 3. The forest-grown trees were 12, 15, 30, and 35 years old (table 1). Of these cuttings, 294 (94%) produced roots. Among the 18 sources, with repeat batches for some sources, rooting ranged from 50 to 100% and was 100% on the 4 forest-grown trees. Average rooting time (time needed for half the batch to produce at least one visible root)

Table 1—*Summary of softwood cutting results for greenhouse, nursery, and forest-grown yellow birch in Vermont in 1976*

Age of parents (yrs)	Growth regulator	Number of cuttings	Rooting percent	Mean time of initial rootings (days)	% Survival in autumn
2	None	5	100	60	0
2–4	Hormodin 3	51	94	53	29
2–8	Strike	166	90.9	48	26
12–15	Strike	72	100	41	60
30–35	Strike	17	100	45	6

was 48 days and ranged from 21 to 60 days among all sources and collections.

The rooting compound Strike (NAA with Captan) yielded 50 to 100% rooting among the 18 sources and 22 batches tested and 95% rooting overall. Hormodin 3, used on 4 sources yielded 62 to 100% rooting and overall rooting of 94 percent.

Development of cuttings following rooting and potting was variable; some cuttings had additional shoot growth but many showed little change except apparent thickening of the original leaves. In September 103 of 294 cuttings were still alive. Fifty of these having good vigor were transplanted to nursery beds, but only 20 survived the winter and grew well the next summer.

1977 trials. In 1977, 2082 cuttings were taken from 27 greenhouse, nursery, and forest-

Table 2—*Parent tree sources, number of cuttings, and percent rooting by compound for softwood cuttings of yellow birch taken in Vermont during the summer of 1977*

Location of parent in Vermont (Clone No.)	Age of parent (yrs)	Total No. of cuttings	No. of cuttings rooted	Percent of cuttings rooted					
				No Hormone	Rootone F	Strike	Hormodin 1	Hormodin 2	Hormodin 3
Essex Jct. Nursery (1001)	5	24	3			12.5		25	0
Essex Jct. Nursery (1002)	5	36	13				25	38	36
Jericho Nursery (1003)	5	25	0		0	0.0	0	0	0
Jericho (1009)	30	117	28		*20	55	0	22	16
Jericho (NH Source) (1010)	15	92	17		11	88	11	13	
Middlebury (1021)	8	61	3		*0	0	0	9	17
Jericho (1022)	35	129	26		*0	20	0	3	64
Sutton (1023)	30	74	2			0		7	0
Sutton (1024)	15	137	59	50	*27	20	0	64	50
Sutton (1025)	15	138	17			24		6	7
Sutton (1026)	15	163	82	50	*20	71	0	46	43
Jeffersonville (1050)	30	21	0			0		0	0
Sutton (1051)	13	127	52		*0	45	0	41	52
Sutton (1053)	15	109	33			24	0	38	35
Essex Jct. Nursery (1054)	6	78	2	0	*10	10	0	0	10
Middlebury (1055)	9	71	15	67	*11	25	0	19	38
Middlebury (1056)	9	71	15	67	*11	25	0	19	38
Jericho (1057)	15	6	3					50	
Sutton (1059)	30	36	5			0		0	45
Grafton (1061)	20	58	0		0	0	0	0	0
Jericho (1062)	30	169	5		*8	2	0	6	0
Jericho (1063)	30	135	44		*32	63	12	21	42
Jericho (1064)	35	40	12			33		14	60
Essex Jct. Nursery (1065)	3	22	18	64				100	
Jericho (1066)	30	36	2			8		0	8
Jericho (1067)	30	17	0		0		0	0	
Jericho (1068)	30	32	27	83	50		100	86	100
Total or Average		2082	490	44	14.5	26.3	7	30.6	28.4

*Source included in ANOVA.
Rootone F values significantly different from Strike and Hormodin 2 and 3 values (P = 0.072).
Hormodin 1 values significantly different from other hormone values (P = 0.05)

grown trees. Of these cuttings 23.5% developed roots and were potted. Rooting ranged from 0 to 86% among the 27 sources, 70 different batches, and 6 different treatments including a control treatment (table 2). Analysis of data for 5 growth regulators applied to 11 different sources indicated that Hormodin 1 resulted in significantly less rooting than the other 4 regulators, whereas Rootone F yielded more rooting than Hormodin 1 but significantly less rooting at P = .072 (table 2). Only 40 cuttings had new shoot growth after potting. All others died in the greenhouse during the fall and winter. The 40 healthy plants were transferred to nursery beds in August, but few survived the winter.

Among cuttings treated with a growth regulator, best rooting (30.6%) was obtained with Hormodin 2 (158 of 517 cuttings). The lowest rooting (7%) was with Hormodin 1 (14 of 199 cuttings). Rootone F yielded 14.5% rooting (25 of 172 cuttings), Strike yielded 26.3% rooting (135 of 514 cuttings), and Hormodin 3 yielded 28.4% rooting (129 of 454 cuttings). Cuttings from seven trees aged 9 to 38 years were treated with no growth regulator and 28 of 63 cuttings (44%) rooted. These cuttings took considerably longer to root than treated cuttings.

Rooting seems to occur best in mid to late summer. Among cuttings from 5 sources taken after July 1, cuttings treated with no growth regulator averaged 44.4% rooting while those treated with a growth regulator averaged 60.4% rooting.

1978 trials. During 1978 cuttings were taken from twelve trees ranging from about 24 to 38 years in age. These trees were growing on a sandy soil at 700 feet elevation in Jericho Nursery, Vermont and on a stony silt loam soil at about 1800 feet elevation in Duxbury, Vermont. Seven to ten batches of 10 to 20 cuttings were taken from each tree at approximately 1-week intervals between June 7 and August 1. All cuttings were treated with Hormodin 2 (0.3% IBA). Of the 1,396 cuttings taken, 17.7% struck roots and were potted. Average rooting percent by source for the season ranged from 4.6% for a tree at Jericho to 47.2% for the best tree at Duxbury (table 3). Trees 4 and 11 had significantly better rooting than all other trees, and tree 6 rooted significantly better than trees 1 and 7.

Among these 12 trees, only three had maximum rooting occur for cuttings taken during June. Five trees had maximum rooting occur for cuttings taken between July 1 and July 20, while

Table 3—*Data summary and analysis variance for rooted cuttings from 12 yellow birch trees in Vermont sampled during the summer of 1978.*

Tree number	Tree age (yrs)	Total cuttings	Total rooted	Average rooting percent	Mean time of initial emergence (days)
1	32	126	7	5.5	48
2	35	140	20	14.3	42
3	38	136	12	8.8	55
4	25	138	47	34.1	46
5	32	109	14	12.8	48
6	38	110	29	26.4	47
7	36	109	5	4.6	51
8	31	96	9	9.4	45
9	35	109	8	7.3	49
10	30	103	12	11.6	47
11	33	108	51	47.2	46
12	28	112	33	29.5	57
Total/average		1396	247	17.7	48

four trees had maximum rooting occur for cuttings taken after July 20. Within individual sources and batches, some cuttings rooted in 27 days while others cuttings showed no sign of rooting after 80 days and the procedure was terminated.

Discussion

During the last two rooting seasons the misting sys tem failed to work for 2 days in midsummer. Leaves of many cuttings turned bronze during this period, and it appeared all cuttings would be lost. Rooting did occur on about 20% of all cuttings taken, however, and some sources and batches had 100% rooting despite the problem, but lack of water most likely reduced rooting success. Imthese studies cuttings were from plants ranging up to 38 years in age. Cuttings from older plants often do not root as readily as from young plants because they lack juvenility characteristics (10).

Overall rooting the first year was 94% for cuttings from seedlings up to 5 years of age and with no mist failures in the greenhouse, 23.5% the second year, and 17.7% the third year. These differences in rooting are influenced by differences in sources; though some sources were the same each year, differences in physiology were affected by current and past growing season, and by greenhouse environment.

In these studies with yellow birch, cuttings from trees up to 5 years old usually root quite well. Cuttings from trees 5 to 15 years of age seem to have lower rooting potential but do root slightly better than those from trees 30 to 40 years of age. Some trees could be considered good rooters while other trees are comparatively poor rooters, despite age or hormone used. A successful vegetative propagation program may thus depend on identifying desirable phenotypes that are good rooters.

The time of year that yellow birch cuttings are taken has a strong influence on rooting success: best rooting occurs during July and August. Cuttings rooted in late summer, however, are not likely to develop sufficient new growth and may present problems in hardening off for overwintering in nursery beds or a cold greenhouse.

Among the commercial rooting formulations (containing either NAA or IBA) used, Hormodin-2 (0.3% IBA) is judged most effective. Hormodin-3 also yielded good rooting results but the stem section coated with the powder often dies and turns black; rooting occurs above this zone. The rooting powder Strike (containing NAA) also yielded good results but is not readily available. Other rooting powders containing NAA may work equally well.

Results of these studies over 3 growing seasons indicate that softwood cuttings from yellow birch can be rooted with reasonable success using commercial rooting formulations and intermittent mist. Rooting varies considerably among trees, with season, and with plant age. Rooting of cuttings from a single tree may also vary from year to year. There are difficulties in having cuttings break bud to form new growth after rooting and in achieving successful overwintering. Preliminary studies indicate that warm root temperatures obtained by using a heated mat may promote budbreak after rooting. In the end, over 100 yellow birch cuttings survived the greenhouse and nursery phases and are now showing good growth following outplanting on forest sites. Though this percentage of survivors is small, it demonstrates that vegetative propagation of yellow birch by rooting softwood cuttings has potential in genetic improvement programs, and for intensive management where a few stems per acre of selected clones may be planted on highquality sites.

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