Effects of Chemical Weed Control and Seedling Planting Depth on Survival and Growth of Aspen[1]

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Deep-planting aspen seedlings by placing the root collar 15 centimeters below the soil surface reduced injury from simazine. Simazine gave excellent weed control, whereas diuron and linuron were not as effective. All three herbicides were toxic to sensitive poplar species, even at low concentrations. Survival was more important than early growth as a criterion for evaluating herbicides for aspen establishment.

Research interest in short-rotation tree plantations for biomass production, spawned by the energy crisis of the 1970's, continues to grow. Species of *Populus* are frequent choices for these plantations in the Lake States because of their fast growth and coppicing ability. Despite their popularity, inexpensive means for establishing such plantations have not been developed for most *Populus* species. Hybrid poplars, cottonwood (*Populus deltoides*), and quaking aspen (*Populus tremuloides* Michx.), along with most other hardwood species, need good site preparation and weed control in the first 2 to 3 years in order to be successfully established on abandoned fields (4, 13, 14). Cultivation is effective but expensive. Chemical weed control is an alternative method that is less expensive but more risky. Improved planting practices that include chemical weed control and exclude cultivation need to be developed and refined for all poplar species, especially the sensitive balsam poplars (*Populus balsamifera* L.) and aspens.

Much of the previous poplar research concerning preemergence herbicides has been directed at the black poplars (Section Aigeiros), balsam poplars (Section Tacamahaca), and their hybrids. Herbicide research on aspen (Section Leuce), however, has been limited. Because aspen is abundant and regenerates easily from established stands, planting it has received little interest in the past. With the recent upsurge of research on energy plantations, however, aspen is now being considered as a possible plantation species.

The work reported here tested the efficacy of three preemergence herbicides--simazine (2-chloro-4,6-bis(ethylamino)-s-triazine), diuron (3-(3,4- dichlorophenyl)-1,1-dimethylurea), and linuron (3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea) -- in controlling weed competition on an abandoned field in southern Michigan. These herbicides have been used previously in poplar plantations by numerous scientists, including von Althen (11, 14), Dickmann et al. (6), and Netzer and Noste (8). In conjunction with these herbicides, deep-planting of the seedlings and the use of plastic mulch were evaluated for protection from chemical injury. The purpose of these treatments was to find a system using chemicals that could be applied to planting aspen on abandoned farmland in Michigan.

Materials and Methods

An agricultural field that had been idle for 25 years was chosen as a planting site. The field is located in Ingham County (S 6 T3N R1W), MI. The soil series, a Marlette fine sandy loam, is classified as a mixed, mesic Glossoboric Hapludalf. The soil properties and chemistry of the Ap horizon were analyzed by the Michigan State University Soil Testing Laboratory. The soil contained 2.0 percent organic matter and 21.3 percent clay. Its pH was 6.7 and the cation exchange capacity was 6 milliequivalents per gram. Its texture class is sandy clay loam. The field was mowed in September 1980 and sprayed with 7 liters of glyphosate per hectare in 1-meter strips. The major vegetation cover at the time of spraying was quackgrass, *Agropyron repens* (L.) Beauv.

Nursery-grown 1+0 seedlings of bigtooth aspen (*Populus grandidentata* Michx.) and quaking aspen that had been lifted in March and stored in a refrigerated room were planted May 8,

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1981, in five to seven tree plots in a randomized block design with seven replications. The trees were spaced 1.2 meters within rows and 2.4 meters between rows. There were eight plots (treatments) per replication. Each plot contained both species of aspen and was randomly assigned one of eight possible treatments (table 1). The dosage (2.8 kilograms of active ingredient per hectare) for all chemical treatments was an arbitrary concentration that fell within the lower range of application rates commonly used for these three herbicides. Optimal herbicide dosages were not tested. Planting procedures consisted of making a slit down each sprayed row with a tree planter and then hand planting the trees in the slit. The root collars of all trees in each treatment plot were placed either 3 or 15 centimeters below the soil surface. In one treatment, a 30-centimeter-square black plastic mulch was placed around each tree.

On May 12, all plots to receive an herbicide treatment were completely sprayed with a 9.5 liter Lofstrand (Model 1730) handsprayer that had been calibrated at 30 to 40 pounds per square inch. The control plots were hand cultivated. Rain (7.6 centimeters) fell on the test site from May 10 to May 15. Rainfall for May and June 1981 was normal. The following April (1982) all plots were sprayed with 2.8 kilograms (active ingredient) of simazine per hectare.

In May 1981, 1 month after spraying, herbicide injury to each tree was rated subjectively. In September 1981, weed control for each plot was evaluated. Tree heights were measured in the fall of 1981, 1982, and 1983. Diameters at 5 centimeters above ground level were measured in 1982 and 1983. Percent survival for each treatment was recorded for all 3 years.

Table 1—*Effects of eight herbicide treatments (2.8 kilograms active ingredient per hectare) on weed control and aspen growth and survival*

		Phytotoxicity		Growth data (treatment means)			
Planting depth	Other treatments	Herbicide injury rating[1] (aspen)	Weed control[2] (%)	1983 Survival (%)	1981 Height (m)	1983 Height (m)	1983 Diameter[3] (cm)
Simazine							
3 cm	—	0.67	87	62	0.67	2.7	3.1
15 cm	—	.12	89	89	.72	3.0	3.5
Regular	Plastic Mulch	.65	82	79	.74	2.7	3.2
Diuron							
3 cm	—	.69	59	77	.76	2.9	3.5
15 cm	—	.72	56	71	.75	3.2	3.5
Linuron							
3 cm	—	1.23	62	55	.69	2.8	3.1
15 cm	—	.92	62	61	.73	3.1	3.4
No herbicide							
3 cm	Cultivation	.00	100	96	.90	3.4	4.0
LSD (0.05)		.35	—	—	.13	—	—
Significance of F value		**	**	*	*	NS	NS

[1]Injury rating was 0 = no damage, 1 = yellow leaves, and 2 = yellow and black leaves.
[2]Percent of sprayed ground without live weeds.
[3]Diameter at 5 centimeters above ground surface.
* and **Significant at the 5 and 1 percent levels, respectively. NS = not significant

An analysis of variance was performed on plot means for each trait except survival and weed control. Herbicide damage ratings were tested for normality before analysis. The survival and weed control data were not normally distributed, so Friedman's two-way classification test (10) was used to detect differences. An LSD test was applied to the treatment means for the 1981 height and herbicide damage data. Correlations between years were generated for treatment means of height and diameter. Nonparametric rank correlations were calculated for the relationship of weed control to the treatment means for height and diameter.

Results

The results for each treatment are listed in table 1. The control and one simazine (deep-planting) treatment had the least herbicide injury and the best weed control. The two linuron treatments had the most initial herbicide damage. Simazine gave better weed control than either diuron or linuron. Deep-planting reduced chemical injury on simazine plots but not on the diuron or linuron plots.

The control treatment had the highest survival in each of the 3 years. One simazine (deep-planting) treatment also had good survival. The two linuron treatments and one other simazine (regular-planting) treatment gave poor survival. Deep-planting increased survival on simazine plots but not on the diuron and linuron plots. Few trees died after the first year; therefore, the survival rankings of the treatments remained unchanged throughout the 3 years.

First-, second-, and third-year heights and diameters were greatest in the control plots. Trees given the simazine (regular-planting) treatment generally showed the poorest height and diameter growth. In the second and third years, trees in the deep-planted plots of simazine, diuron, and linuron grew more than the regularly planted plots. This trend was also true for diameter except that there were no differences in diameter of trees in the diuron plots for the third year. The seedlings that were deep-planted appeared to suffer no detrimental physiological effects from the placement of the root collar 15 centimeters below the soil surface. This observation agreed with that of Benson (4), who reported that deep-planting aspen 10 to 30 centimeters above the root collar did not affect their establishment adversely.

Treatment means for height and diameter were significantly correlated at the 1-percent level between years 1981-82 and 1982-83 and at the 5-percent level for years 1981 and 1983 (table 2). Nonparametric rank correlations between weed control and growth data were low (r = .05 to 0.20) and nonsignificant at the 5-percent level of probability.

Discussion

Three years' results of height and diameter growth for each treatment indicate that cultivation alone was superior to all chemical treatments, but the differences became insignificant after the first growing season. The smaller and less significant correlation (table 2) of the treatment means for height between years 1981 and 1983 indicate that first-year treatment differences were decreasing with time, that is, the mean height of the poorest treatment increased from 74 percent (1981) to 79 percent (1983) of the mean

Table 2—*Year-to-year correlations of the treatment means for height and diameter of the experimental aspen seedlings* (df = 7)

	r	
Years correlated	Height	Diameter
1981 with 1982	0.84**	—
1981 with 1983	.77*	—
1982 with 1983	.97**	.95**

* and **Significant at the 5- and 1-percent levels, respectively.

height for the best treatment (table 1). The initial superiority in growth and survival of cultivated trees was attributed to the absence of both weed competition and phytotoxic effects from the chemical treatments, as well as increased soil aeration.

Simazine, diuron, and linuron are toxic to sensitive poplar species at low concentrations. These chemicals are principally taken up by root absorption. Jaciw (personal communication) observed in Ontario that deep-planted hybrids of white poplar (*P. alba*) and aspen were not damaged by simazine. Therefore, preventing contact of the root system with the herbicide is essential for establishing chemical-sensitive species such as aspen.

Roadhouse and Birk (9) found that simazine applied at a rate of 2.2 kilograms (active ingredient) per hectare on a cultivated field did not penetrate below the top 15 centimeters of soil during the first growing season. In addition, Weldon and Timmons (15) showed on a sandy clay loam and a loamy sand soil that diuron, when applied at rates of 2.2 and 4.5 kilograms (active ingredient) per hectare does not penetrate below 10 centimeters in the soil regardless of the amount of irrigation used. These findings suggest that deep-planting aspen seedlings 15 centimeters below the soil surface should minimize herbicide contact with the root system. The results with simazine here support this hypothesis. The one simazine (deep-planting) treatment had 89 percent survival after 3 years compared to 62 percent for the other simazine (regular-planting) treatment.

The diuron and linuron deep-planting treatments may fail to prevent herbicide injury because these two chemicals are more water soluble than simazine and are also absorbed by the foliage. The water solubility of simazine is 5 parts per million (2), compared with 42 for diuron and 75 parts per million for linuron (1). The planting slit may have opened slightly because of soil shrinkage from evapotranspiration; the soil texture of the Ap horizon contained 21 percent clay, which increases the soil shrinkage properties (12). During May, heavy rains could have carried more of the more water-soluble herbicides (diuron and linuron) down into the slit than the highly insoluble simazine.

Another possible reason for the increased damage in the diuron and linuron deep-planted treatments is that substituted urea herbicides, in contrast to simazine, are more readily absorbed by the foliage (1, 5, 7). At the time of the herbicide treatment, a few trees in each plot had new leaves just breaking through the bud scales. No attempt was made to cover the seedlings when each plot was sprayed because the spraying procedure was to simulate actual field application conditions. These early leafing seedlings suffered foliage injury and may have absorbed sufficient herbicide to kill them.

The effectiveness of plastic mulch in controlling chemical injury was intermediate when compared to the two simazine treatments. The plastic mulch (simazine) treatment had poorer survival than the deep-planting (simazine) treatment but better survival than the regular-planting (simazine) treatment. Although the plastic lessened simazine injury, it did not prevent it. The main problem with the plastic was that it collected and pooled the herbicide spray and then funneled some of the chemical through the plastic at the opening around the root collar. The use of plastic mulch around individual stems to prevent herbicide damage should be reevaluated because of its cost in labor and materials as well as its uncertain effectiveness.

The good to excellent (82 to 89 percent) weed control produced by simazine compared to the moderate (56 to 62 percent) weed control exhibited by diuron and linuron was due largely to the chemistry of the herbicides. The low soil organic matter (2.0 percent) and the slightly acidic pH (6.7) of the Ap horizon were favorable for chemical activity of all three herbicides. However, under these conditions simazine gave better weed control, partly because simazine-tolerant late-season grasses did not invade the simazine plots in late summer. Simazine was probably more persistent in the soil because it was more insoluble and less volatile than diuron and linuron.

Achieving excellent weed control (75 to 100 percent) by using moderate to high application rates of chemicals such as simazine may not be advisable because of the increased risk of mortality. This was the case with the simazine plots, which averaged 86 percent weed control compared to 60 percent for the diuron and linuron plots. Despite having better weed control, simazine (regular-planting) plots had poorer survival and growth after 3 years than did the diuron (regular-planting) plots.

The absence of significant correlations between first-year weed control and the 3 years of growth data suggested that the initial weed control, which was as low as 35 percent in some plots, was sufficient to avoid serious growth inhibition from weed competition. This lack of correlation between weeds and growth agreed with the results of Benson and Einspahr (3), who found that, when greater than 50 percent of the vegetative cover was controlled, low survival or reduced tree growth resulted, presumably from chemical toxicity. They concluded that complete control of weeds is not necessarily a good criterion of usefulness of herbicides. These results imply that prevention of herbicide injury while still achieving good survival and growth is a better strategy than trying to control all weeds. Therefore, on an average or better site, aspen can be successfully established even if weed control is 50 percent or less for the first growing season.

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Yellow-Poplar and Black Cherry Grow Well After Underplanting and Release

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Yellow-poplar and black cherry were planted on the MidCumberland Plateau under a poor quality oak stand that was injected with herbicide 6 weeks later. Survival and growth have been excellent. After 7 years, the yellow-poplar has overtopped and nearly eliminated competing trees. Black cherry will need cleanings to reach harvest age.

Thousands of acres of upland hardwoods are so degraded that they presently have little commercial value. On some tracts, it may be desirable to replant with fast-growing species. Russell (3) presented yellow-poplar (*Liriodendron tulipifera* L.) as an excellent plantation species if handled properly. Carvell (1) and McGee (2) described how degraded stands can be successfully converted to yellow-poplar by poisoning the overstory a week or two before planting yellow-poplar. We planted as usual and then varied the method slightly by injecting herbicide after the commencement of the growing season. We had outstanding success in establishing yellow-poplar and successfully established black cherry (*Prunus serotina* Ehrh.), another high-value species, by the same method.

Materials and Methods

The site chosen for planting is a head-of-hollow depression in the Mid-Cumberland Plateau near Sewanee, TN, classified as Land-type #1 (5). The sides of the depression sloped about 5 percent, and the bottom was rounded. Soils on the site ranged from 35 to 45 inches deep with a texture that ranged from sandy loam to heavy silt loam over sandstone.

The stand was dominated by scarlet, white, and chestnut oaks (*Quercus coccinea Muenchh., Q. alba* L., *Q. prinus* L.) that remained from a century of highgrade logging. A site with a similar history under the same ownership, logged a few months earlier, yielded an average of one merchantable sawtimber tree per acre. The study site was not logged before planting.

The area was planted in 8- by 8foot spacing; it was divided into 100 plots; 9 trees per plot, with a buffer row between each plot. The seedlings were nursery-run 1+0 stock of unknown seed source. The yellow-poplar averaged about 18 inches high, the black cherry, about 12 inches. Both species were root-pruned to about 8 inches for easy insertion in the planting holes made with KBC planting bars. The seedlings were planted during the first week of April 1977, and the overstory was injected 6 weeks later, after the trees had leafed out. All stems over 1 inch in diameter were treated. Incisions spaced 3 inches edge-to-edge received 1 milliliter of undiluted 2,4-D. A 40-foot-wide buffer strip around the planted area was also treated. The few red maple (*Acer rubrum* L.) present were treated with picloram (Tordon 101). In late June of the second year, the few surviving overstory trees were retreated, and the entire area was lightly weeded by lopping sprouts, mostly sassafras [*Sassafras albidum* (Nutt.) Nees] that were overtopping the yellow-poplar and black cherry saplings.

At the end of the seventh growing season, the heights and diameters of the three stems in the middle row of each plot were measured, and the planted trees in each plot were counted for survival. The number of competing stems greater than 1 inch diameter at breast height (dbh) within the nine-tree plot were noted by species.

Results and Discussion

Although we did not actually measure the seedlings, we noted that first-year growth was more than double the 6 to 12 inches of height growth normally observed for yellow-poplar and black cherry. The herbicides were volatile enough to curl the leaves on a few of the yellow-poplars planted near injected trees. It is not known whether any mortality is attributable to the herbicide, but overall survival was so high that it could not have been important.

Now, after seven seasons, most of the killed overstory has fallen, and remarkably little damage to the new stand has occurred. Those study trees that were broken have resprouted and have nearly regained their former crown position in the stand.

At age 7, survival rates were 95 percent for yellow-poplar and 92 percent for black cherry (table 1). No plot lost more than one-third of its trees. The height of yellow-poplars averaged 24 feet, that of black cherry trees, 18 feet. The height growth of yellow-poplar compares favorably (4) with that of yellow-poplar planted on cove sites (site index = 90 to 110 feet). The black cherry grew well, although a great many trees had crooked or forked stems. Diameters averaged 2.6 inches for yellow-poplar and 1.5 for black cherry.

The black cherry plots supported an average of 8.3 competitors larger than 1 inch dbh or 628 competing stems per acre. Only 3.9 persisted on the yellow-poplar plots (294 stems per acre). The yellow-poplar have overtopped and suppressed nearly all competition, whereas the black cherry are codominant with their competitors. We can expect the sassafras, black locust (*Robinia pseudoacacia* L.) and several other competitors to fall behind black cherry. However, oaks and natural yellow-poplar present a serious threat and, if not soon removed, will overtop and eventually suppress the black cherry near them. At another black cherry plantation (6), less than a mile away on a similar site, that was cleaned periodically until it was 10 years old, the 18-year-old cherry trees are being overtopped by oak and yellow-poplar. Unless cherry plantations are periodically cleaned, very few trees will grow to saw-log size. Yellow-poplar, on the other hand, probably will do well without weeding.

Table 1—*Average survival, height, diameter, and competing stems over 1 inch dbh per acre of 7-year-old underplanted and released yellow-poplar and black cherry*

	Survival (%)	Height (ft)	dbh (in)	Competition (No. trees/acre) Total	Threatening species[1]
Yellow-poplar	95	24	2.6	294	13
Black cherry	92	18	1.5	628	137

[1]The oaks and, in the case of black cherry, natural yellow-poplar.

Conclusions

Underplanting and release in the same year by injection of the overstory appears to be an excellent method for establishing yellow-poplar and black cherry, but planting areas need to be cleaned for black cherry trees to reach merchantable size.

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Rhizomes for Vegetating and Stabilizing Steep Forest Road Banks[1]

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On a woods road cut bank no natural vegetation had become established during the first growing season wherever the slope exceeded 100 percent. Horizontally planted, 12-inch segments of hay-scented fern rhizomes appear promising for stabilizing soils on steep slopes.

In mountainous terrain, logging roads and road banks are often the primary source of stream siltation (5,6). The principle objectives of revegetating logging roads and banks are protecting stream quality by controlling erosion and siltation, and keeping drainage ditches from filling in. In addition, stabilizing inactive logging roads and banks ensures that they will be of future service with minimum upkeep or grading.

The slope angle of the road bank on the uphill side of a logging road largely determines soil stability, because both natural and artificially seeded vegetation rarely become permanently established on steep slopes, those with 100 percent slope or greater (4). Although seeds will often germinate on steep slopes, seedlings wash out when surface runoff and raindrops detach surface soil particles. Some natural revegetation on such banks occurs when mats of litter containing roots of woody and herbaceous plants break away from the top of the bank, lodge and take root on the slope below. Only after many years, however, when erosion at the top of the bank has reduced the percent slope, does natural vegetation from seed become permanently established.

Because of the threat of erosion and the resulting stream sedimentation, roads and banks should be revegetated quickly (4,5). In some instances soil disturbed by logging road construction and use must be stabilized by seeding grasses and legumes, but most level areas and gentle slopes quickly seed-in with natural vegetation. Identifying those areas that need special treatment and those that will seed-in naturally gives a more effective and, in the long run, a much less expensive soil stabilization program for roads and road banks.

Different plants vary in their ability to control erosion (3). Grasses and other plants with a dense, fibrous, lateral root system are much more effective at preventing soil detachment than are species with tap roots (1). With most shrubs, a companion species of some fast-growing plant is often needed to stabilize the soil until these woody plants are well established and completely occupy the site (3).

Perennial rhizomes of certain native forbs form a dense network of roots just beneath the soil. We decided to test certain native species, noted for their ability to rapidly colonize and form quick cover. These species were tested for their ability to stabilize soils on selected portions of road banks (exceeding 100 percent slope) along a newly constructed woods road at the West Virginia University Forest in northern West Virginia. We selected hay-scented fern, *Dennstaedtia punctilobula* (Michx.) Moore; New York fern, *Thelypteris noveboracensis* (L.) Nieuwl.; and whorled loosestrife, (*Lysimachia quadrifolia* (L.) for this study. These aggressive native species colonize road banks with moderate slopes and thrive under a variety of conditions of light and moisture.

The purpose of this study was to determine the best method of establishing these plants, their survival, and rate of spread on steep road banks where natural regeneration is sparse and temporary.

Plot Establishment

In June 1981, test plantings were established on a road bank at the West Virginia University Forest. This woods road had been constructed in November 1979, but the steeper parts of the road bank had not seeded-in with natural vegetation.

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[1] Station Paper No. 1856, published with the approval of the Director of the West Virginia Agriculture and Forestry Experiment Station.

Colonies of the test species were located, and these plants were dug by hand to secure large lengths of rhizomes. These were stored in moist sphagnum moss until planting.

The 12 planting treatments varied by species. Similar treatments were used for hay-scented fern and whorled loosestrife: 6-inch rhizome segments planted vertically and horizontally, and 12-inch rhizome segments planted vertically and horizontally. New York fern, because of its delicate rhizomes, had slightly different treatments. In addition to the hand 12-inch rhizomes planted horizontally, small bundles (hanks) of rhizomes were planted horizontally, and golf-ball-sized rolls of rhizomes were also used.

Four planting sites-areas that had failed to seed-in with natural vegetation due to the steep slope-were randomly selected on steep road banks with exposed soil. On each site, randomly spaced plots were located for the 12 treatments. Each plot contained a checkerboard planting of 36 rhizomes. These were firmly planted in the clay loam soil at a 1-inch depth, except for the vertical plantings where the top of the rhizome was $^1/_2$ inch from the soil surface. Plots extended from the top to the toe of the road bank, a distance of 6 to 8 feet.

Analysis and Results

In July, August, and September 1981 and June 1982 each planting was counted. The August inventory yielded the highest sprouting percentages for most of the treatments (table 1). September counts were lower because some ferns had begun to yellow and die down in late summer, and some withered fronds had disappeared, making the August figures the most reliable of the first-year counts. June 1982 evaluations only gave an indication of survival and vigor because some fronds, particularly those of hay-scented fern (fig. 1), come up slowly in late spring.

The August 1981 measurements were compared using preplanned orthogonal contrasts. These tests (table 2) show where significant differences between species and planting methods exist. The average number of fronds per planted rhizome for the four planting blocks by months, species, and treatments are given in table 3.

Discussion

Rhizome carbohydrate levels are known to show seasonal fluctuations (2). In our study, the rhizomes were planted in June, soon after fronds had developed, so that carbohydrate levels were at their annual low after frond emergence. This may have decreased the vigor and number of sprouts.

Soil nutrient levels were not examined, but they may have been an important factor affect-

Table 1—*Percentage of planted rhizomes with one or more plants averaged by species and treatment*

	1981			1982
	July	August	Sept.	June
Hay-scented fern				
6-in Vertical	12.5	14.6	14.6	8.4
12-in Vertical	14.6	20.1	19.4	7.0
6-in Horizontal	22.2	34.0	32.6	13.2
12-in Horizontal	37.5	50.7	48.6	20.8
New York fern				
Hank	26.4	33.4	33.3	29.2
Ball	18.1	29.2	30.6	20.2
6-in Horizontal	20.2	25.7	25.0	11.1
12-in Horizontal	31.2	39.6	35.4	29.2
Whorled loosestrife				
6-in Vertical	2.1	7.0	9.0	9.0
12-in Vertical	4.9	11.8	10.4	10.4
6-in Horizontal	12.5	24.3	27.1	16.7
12-in Horizontal	9.0	29.2	29.8	21.5

Figure 1—*Hay-scented fern, 12-inch horizontal planting, exhibiting good sprouting and vigor.*

ing survival. Road bank cuts consist of exposed subsoil, which is often lower in essential nutrients than surface soil. Thus fertilizer application might have substantially improved the vigor and growth of planted rhizomes.

Moisture is another important factor. Because all blocks had essentially the same aspect, northwest to northeast, slope was the only variable we examined influencing soil moisture. Horizontal plantings had the advantage of greater surface moisture. In horizontal planting it was also easier to firm the soil tightly around the rhizome, a difficult problem with vertical planting.

In 1982 it was noted that pieces of root mat (that is, soil interlaced with fern rhizomes) had frequently become detached from the top margin of the slope and moved down the bank surface. Where the slope was gentle, these had lodged and rooted. On the steeper banks these often accumulated at the bottom of the slope. Once they had rooted, these acted as centers of spread for ferns and constituted an important type of natural establishment of vegetation on cut banks. Those sprouting rhizomes present the second year appeared to be the same rhizomes that had sprouted in 1981. Few if any of the inactive 1981 rhizomes sprouted in 1982. Horizontally planted rhizomes appeared to sprout only from their tips in 1981, but in 1982 they also sprouted from other points.

Signs of bank stabilization were evident within the blocks of fern plantings. In many cases, areas with planted fern rhizomes appeared as islands of raised soil, for nearly 2-inches of soil had eroded from the surrounding unstabilized areas.

Summary

On the cut bank of a woods road, established in 1979, no natural vegetation had become established during the first growing season wherever the slope exceeded 100 percent. Horizontally planted, 12-inch segments of hay-scented and New York fern rhizomes appear promising for stabilizing soils on steep slopes where natural vegetation has not seeded-in.

Hay-scented fern, because of its more robust rhizomes, showed the highest survival and greatest propensity to colonize these areas of disturbed soil. New York fern appeared less aggressive but was more effective than whorled loosestrife in both rate of survival and vigor.

Table 2—*Orthogonal contrasts and F values for sprouting and vigor means.*

Orthogonal contrasts	Calculated F value	
	Sprouting	Vigor
1. New York fern vs. hay-scented fern and whorled loosestrife	3.16	7.88**
2. Hay-scented fern vs. whorled loosestrife	4.42*	30.96***
3. New York fern hank & ball vs. New York fern, 6- & 12-inch horizontal	.07	.12
4. New York fern hank vs. New York fern ball	.09	3.74
5. 6-inch Treatments vs. 12-inch treatments	2.93	7.87**
6. Vertical treatments vs. horizontal treatments	20.97***	24.61***
7. Contrast No. 6 x contrast No. 5	.46	2.24
8. Contrast No. 1 x contrast No. 5	.16	.20
9. Contrast No. 2 x contrast No. 5	.81	2.20
10. Contrast No. 2 x contrast No. 6	.28	5.34*
11. Contrast No. 2 x contrast No. 6 x contrast No. 5	.28	.80

* Calculated F greater than critical F 0.05 (4.14).
** Calculated F greater than critical F 0.01 (7.47).
*** Calculated F greater than critical F 0.001 (13.09).

Table 3—*Average number of fronds per planted rhizome for the four rhizome planting blocks by month, species, and treatment*

	1981			1982
	July	August	Sept.	June
Hay-scented fern				
6-in Vertical	0.15	0.32	0.37	0.18
12-in Vertical	.24	.50	.51	.11
6-in Horizontal	.34	.72	.86	.31
12-in Horizontal	.50	1.40	1.49	.58
New York fern				
Hank	.35	.93	.99	.87
Ball	.20	.59	6.60	.42
6-in Horizontal	.25	.56	.58	.81
12-in Horizontal	.51	1.08	.92	.65
Whorled loosestrife				
6-in Vertical	.03	.09	.10	.11
12-in Vertical	.06	.14	.12	.12
6-in Horizontal	.14	.28	.30	.24
12-in Horizontal	.09	.42	.45	.26

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Grading Northern Red Oak Planting Stock

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A system for morphological grading of red oak nursery stock, based on stem diameter and length, stem form, buds and roots, is described.

During planting experiments from 1976 to 1982 (11), some 16,000 northern red oak (*Quercus rubra* L.) seedlings, mostly 2+0 nursery stock, were graded to obtain uniform size and form. The trees were supplied by the nurseries of the Ontario Ministry of Natural Resources. About 40 percent of these in any 1 year of planting were of unacceptable quality. On a provincial scale, this would represent an average of 134,000 of the 336,500 seedlings produced each year in ministry nurseries (9). It became apparent that morphological grading of planting stock would be necessary in addition to the rather minimal standards for planting stock size, as recommended for average sites in Ontario (12). Procuring acorns from local trees with desired phenotypic characteristics (5, 6) should also be a minimal practice in hardwood tree improvement programs. It is the purpose here to suggest improved grading standards for red oak to be used in field plantings in southern Ontario.

The grading criteria are based on root-collar diameter and stem length (table 1) and stem form, bud number, and roots of large and small 2+0 nursery stock (figs. 1 and 2). Stock should be graded in nurseries before bundling or on a planting site to avoid the cost of planting inferior stock, which will perform poorly.

Table 1—*Provisional root-collar diameter and stem length grades for 2+0 red oak nursery stock*

Seedling size	Root-collar diameter (mm)	Stem length (cm)
Large	7.5–8.5	55–75
Small	4.5–6.5	30–45
Cull	< 4.5	—

Stem Diameter and Stem Length

Stem diameter and stem length are the criteria with the greatest variations among nurseries, years, and seed sources and should be the basis for judging quality of planting stock (8, 14). In Ontario plantings, root-collar diameter and stem length were reliable indicators of relative growth potential regardless of age of stock (12). A caliper of 8 millimeters, measured 2 centimeters above the root-collar, and a shoot length from 50 centimeters to 1 meter have been recommended for red oak (3,4).

I have observed in numerous plantations that rabbits tend to clip plants of about 6.5 millimeters stem diameter or less often to ground level, leaving a stump that seldom resprouts because it has no dormant buds. This is usually the case with 1+0 nursery stock of small root-collar diameter. Larger diameter stock, however, is seldom clipped to the ground level, and dormant buds are left along the lower stem and near the root-collar, thus allowing resprouting. When clipped seedling stock resprouts, the growth of the sprout will be more vigorous on larger diameter stumps than on smaller ones.

Stem Form

The stem should be well defined and straight, with relatively short branches on the previous year's growth. Long branches (fig. 1, sample 5) should be pruned and multiple leading shoots should be pruned to leave the sturdiest shoot (fig. 2, sample 6) on seedlings that have met all other criteria. I have observed that thin whip-like long stems (fig. 1, sample 6; fig. 2, samples 7 and 8) usually grow very slowly. Seedlings with multiple stems should be culled and the sources of acorns that do poorly identified (7).

Buds

The stem should have numerous buds, especially on the last year's growth, and a cluster of buds at the apex. Buds should not be swollen or flushed at the time of planting. Acorns from more southerly sources tend to produce seedlings that flush early

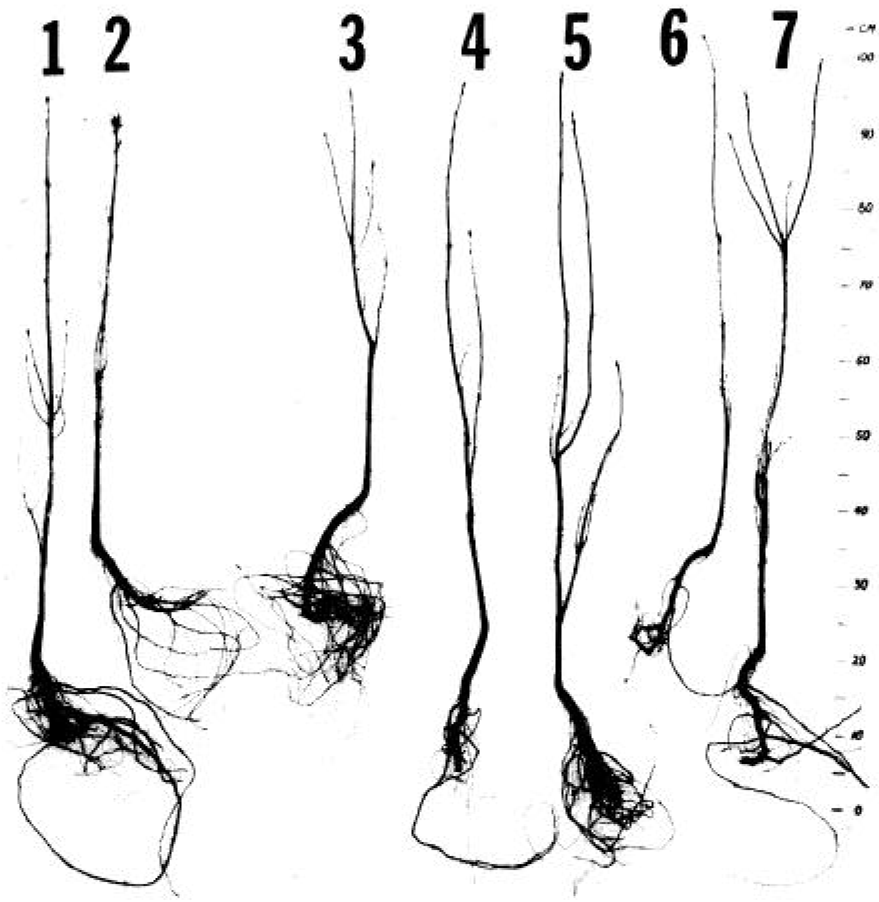

Figure 1—*Large 2+0 nursery stock of northern red oak after lifting.*
Class 1—*Seedlings 1 and 2 (acceptable). Leading shoot is well defined, sturdy, and straight with buds on most of stem. Branches are relatively short, mainly on previous year's growth.*
Class 2—*Seedling 3 (acceptable). Leading shoot less defined and less sturdy than grade 1 with fewer buds and more prominent branches.*
Class 3—*Seedings 4 and 5 (acceptable). Leading shoot is thin or forked with prominent branches. Large root-collar diameter ensures resprouting when stem is decapitated or injured due to browsing or girdling. Prune branches, particularly the upper branch on 5.*
Class 4—*Seedlings on 6 and 7 (culls). Stem is very thin with questionable resprouting capacity when decapitated or injured and/or tendency to forking prominent.*
Root pruning. *Tap root should be pruned to 20 to 25 centimeters length and lateral roots to 10 to 15 centimeters length (to facilitate spreading out roots in planting hole).*

and are thus more susceptible to frost damage. An important and consistent difference between geographic sources in red oak has been found in the dormancy requirements (7, 13).

Roots

Undercutting of roots before seedlings are lifted from the nursery beds shortens the tap root, often resulting in a "hockey stick" root but leaving most of the lateral roots up to 1 meter long intact. Although this undercutting may not affect the vigor of a young tree, the weight of the developing crown cannot be properly supported and mechanical damage to the roots may result after outplanting, as found in several coniferous species (2). In addition, such bent roots may be more susceptible to root rot, as found in planted white spruce (10). Because seedlings develop new roots soon after planting, additional pruning of lateral roots is good practice to prevent long roots from being placed close to the surface of a conventional planting hole. Pruning to about 20 to 25 centimeters is therefore recommended for red oak to facilitate field planting and ensure a high rate of survival (4, 6).

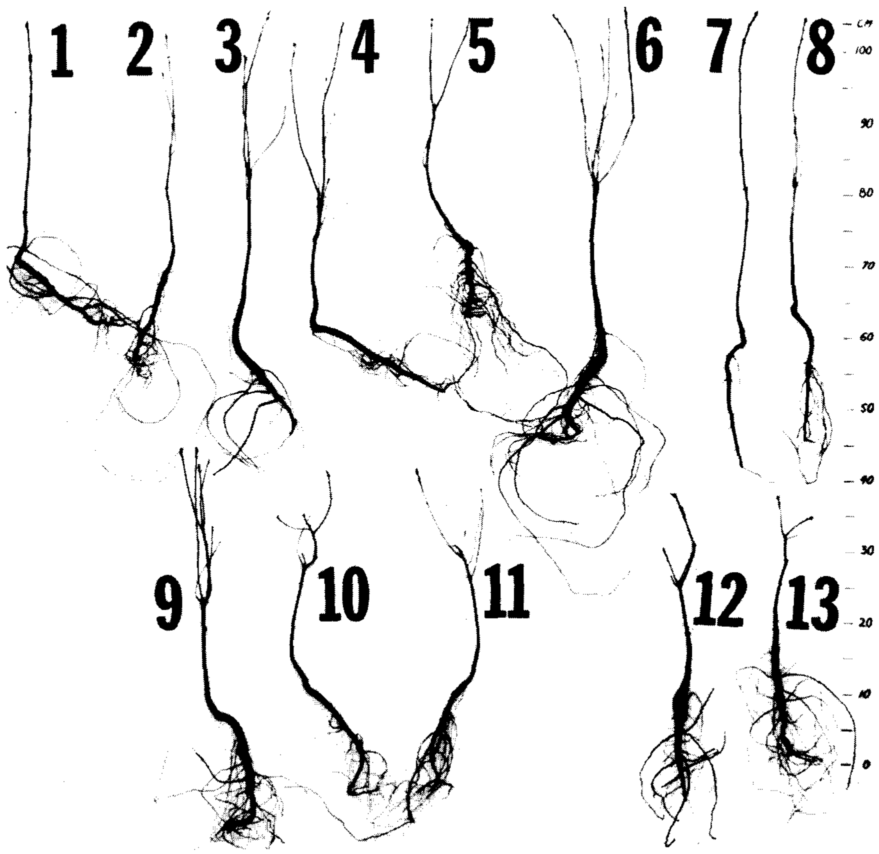

Figure 2—*Small 2+0 nursery stock of northern red oak after lifting.*
Class 1—*Seedling 1 (acceptable). Leading shoot sturdy, straight with buds on most of stem. Branches usually absent.*
Class 2—*Seedlings 2 and 3 (acceptable). Leading shoot less sturdy than grade 1. Branches sometimes relatively too long as in 3.*
Class 3—*Seedlings 4 to 6 (acceptable). Stem with 2 to 3 leading shoots. Ensure presence of terminal buds on the sturdiest shoot and prune the remaining ones.*
Class 4—*Seedlings 7 to 13 (culls). Stem of poor form, very thin, tendency to forking prominent.*
Root pruning. *Tap root should be pruned to 15 centimeters length and lateral roots to 10 centimeters length (to facilitate spreading out roots in planting hole).*

Conclusion

Red oak nursery stock can be graded by assessing relatively easily observable criteria. Stock of better quality should improve the performance of red oak plantations in Ontario. This should also strengthen the confidence in propagating oak where it grows faster and is of better quality than, for example, sugar maple (1). Use of acorns from selected local phenotypes should also be a standard practice to maximize propagation of sources with rapid juvenile growth and other important characteristics.

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Evaluation of Time-Temperature Monitors for Control of Seedling Storage

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*i - Point time-temperature monitors (TTM) were evaluated for their use as quality indicators for loblolly pine (*Pinus taeda *L.) seedlings. TTM indicators activated at the time of seedling packing accumulate the effects of time and temperature during seedling storage and change color when specified limits are exceeded. TTM indicators have considerable potential as a quality control method for seedling storage. The greatest limitation in their use is the lack of good data on the storage time-temperature relationships for tree seedlings. As nursery workers gain experience with them, TTMs should become important for monitoring seedling quality in storage.*

From the time of packing at the nursery until transplanting in the field, tree seedlings are subjected to a variety of environmental conditions that may ultimately affect their survival and growth.

Normally, seedlings are immediately placed in cold storage (33 to 38 °F) after packing for a 48hour (minimum) cool down period. Later, seedlings are moved from this cold storage unit through the open air and loaded onto a refrigerated truck for transportation to field units. On arrival at the field units, seedlings ,are again moved from refrigerated transport through open air into a second refrigerated storage building. Seedlings remain in this refrigerated building until the day of transplanting. On the day of transplanting, seedlings are removed from refrigeration and may be kept for several hours at outside temperature before finally being transplanted.

During this storage and transportation process, which may last as long as *4* to 6 weeks or more, seedlings may be subjected to a variety of temperatures. Normal cycling of cooling units, variation of temperatures within the units, malfunctions, and improper loading and stacking techniques are some of the reasons for these variations.

To further complicate the problem, the several different people usually involved in the process are unaware, at least in part, of the way the seedlings have been handled.

Recording thermometers are placed about in the centers of cold storage buildings to monitor temperature. These thermometers do not, however, monitor the conditions at the location of each seedling bag. These thermometers do not accumulate storage time of seedlings and are not available in most transport units.

Because of these shortcomings, some type of device is needed to monitor and accumulate data on the treatment of each bag of seedlings and indicate if and when specified limits were exceeded.

Materials and Methods

A time-temperature monitor (TTM) keeps track of the accumulated time and temperature to which a perishable substance is subjected, from the time of harvest until use. The i-Point TTM is an inexpensive monitor designed to integrate time and temperature during storage and transport of any perishable product. The small indicator accumulates all temperature experiences. When a preselected time-temperature limit is exceeded, the TTM will react with an irreversible color change. This color change serves as an early warning system, indicating that some action must be taken to prevent product loss.

Five-thousand i-Point TTM indicators were obtained from i-Point Technologies Ltd. (Washington, DC). Type 2220 was selected for our tests. At 32 °F temperature, the color of this monitor changes at 18, 22, and 28 days. Loblolly pine seedlings in the Ashe Nursery at Brooklyn, MS were lifted in late December 1983 and January 1984 and packaged in K-P bags. As soon as a bag was strapped and tagged (date, seed source, and destination), a TTM was activated and attached to the bag where it could be seen readily during storage. These indicators were checked for color change at specific times during the storage and handling process.

Results

A number of the seedling shipments were received in the field and were outplanted before any color changes were noted on the TTMs. However, several shipments were held until changes to colors 2 and 3 occurred (table 1). Seedlings shipped to Districts A and B were planted soon after the change of the TTM to color 2. In these two shipments the temperatures related well to length of storage. Seedlings shipped to District C took 24 days to change to color 2, indicating that they were stored at lower temperatures, averaging about 30 °F. A check of the records indicated that temperatures were lower than planned.

Seedlings at District D reached color 2 in 12 days. The temperature must have been at about 45 °F for the color to change this early in storage. Records confirmed that the unit was not cooling properly. The results do show that TTM can serve as a quality-control technique for seedling storage. However, because these results were not correlated with field performance, the color changes could not be related to seedling survival.

Table 1—*Color change in loblolly pine seedlings shipped to four ranger districts*

Ranger district	Lifting date	Average days for color change		Integrated storage temperature (° F)[1]
		Color 2	Color 3	
A	12/20/83	14	-	39
B	12/20/83	16	-	41
C	1/12/84	24	-	30
D	1/12/84	12	16	45

[1]Determined from the curve of TTM Type 2220.

Conclusions

Preliminary studies of i-Point TTM indicators show that they have good potential for use in quality control of seedling storage. At this time, however, there is not enough biological information to specify the type of TTM indicator that closely relates storage conditions to field performance. Further research is needed to develop these relationships.

Even without this information, TTMs can be useful in monitoring seedling storage as a means of detecting the effects of cooler failures, lengthy storage, or both. In fact, they will integrate the effects of both of these variables and alert the silviculturist of problem situations that require immediate action.

The psychological effects of the TTM may be one of its greatest values. Because of its presence, personnel are seemingly more aware that seedlings are perishable products and must be cared for properly. This awareness results in closer inspection and greater care of seedlings.

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Wetting Agent in the Planting Hole Reduced the Effect of Seasonal Drought on Douglas-Fir Container Stock

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The use of a wetting agent in the planting hole with Douglas-fir 1+0 plugs provided significant relief of moisture stress and reduced mortality compared to control seedlings during an 8-week drying cycle. A cost-effective means of application remains the major operational limiting factor.

Many Douglas-fir plantation failures on the east side of Vancouver Island, BC, result from seedlings being ill prepared for their first season of drought. Improved stock quality, handling, and timing of planting are needed. In the interim, use of a slow-release water source in or near the planting hole could alleviate some of these plantation failures. A wetting agent may provide sufficient slow-release water to pull many seedlings through their first critical season.

The objective of this trial was to test three levels of a wetting agent known as Aquakeep (Mitzuta Ind., Vancouver, BC), a polyacrylamide powder that can absorb up to 400 times its weight in water and release it more slowly than water bound to surrounding soil particles.

Methods

This experiment was designed as a completely randomized block with 3 replicates of 4 treatments and 25 seedlings per treatment. The four treatments consisted of four levels of Aquakeep in the planting hole (0, 0.125, 1.0, and 3.0 grams). The seedlings, 1+0 Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) containerized seedlings from a single seed source and nursery, were dibble planted into 15-centimeter-diameter pots. The potting medium consisted of 2 parts peat/1 part perlite/1 part coarse sand. The Aquakeep treatments were applied in powder form at the time of planting into the dibble hole. All seedlings were maintained at field capacity until 90 percent budburst had been achieved. At that point water was withdrawn.

The growing environment was a heated and vented glass greenhouse set to provide a 22 °C (±5 °C) day/night environment with a 16-hour photoperiod at approximately 500 microeinsteins. An additional subset of seedlings (40 seedlings per treatment) was used to assess predawn plant moisture stress (PMS) during the drying cycle (five seedlings per treatment per week).

All seedlings were assessed for survival weekly. Trees were a *priori* defined as dead if greater than 50 percent of their foliage was brown.

Results and Discussion

The results indicate that the presence of a wetting agent in the planting hole significantly decreased plant moisture stress and significantly delayed the onset of mortality (table 1, Figs. 1 and 2). In general, the more wetting agent present, the greater the delay in moisture stress and mortality. However, two important observations were made regarding optimum quantities of Aquakeep. It was evident during the destructive sampling that the wetting agent was acting as a water source while it remained wet. However, once it dried, it appeared to begin to act as a dessicant and may have begun to draw moisture from the seedling root system. This type of effect may explain the discontinuities in the PMS curves (figs. 1 and 2) for both the 0.125-gram and 1.0-gram treatments.

Table 1—*Analysis of variance significance table for treatment (Aquakeep) effects on plant moisture stress and survival for 8 weeks*

Factor	1	2	3	4	5	6	7	8
Plant moisture stress	**	***	***	NS	NS	**	NS	NS
Survival	NS	NS	NS	NS	NS	NS	**	*

*Significant at P = 0.1.
**Significant at P = 0.05.
***Significant at P = 0.001.
NS - not significant.

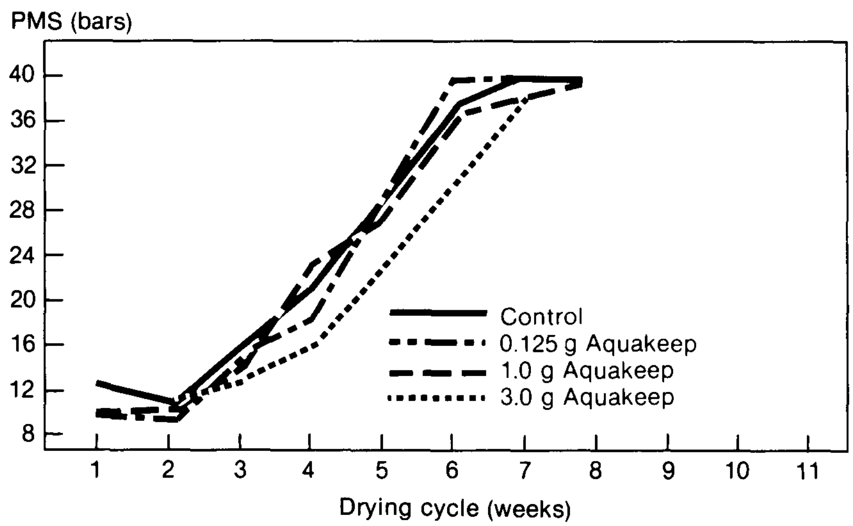

Figure 1—*Weekly mean moisture stress for Douglas-fir container seedlings treated with Aquakeep during an 8-week drying cycle*

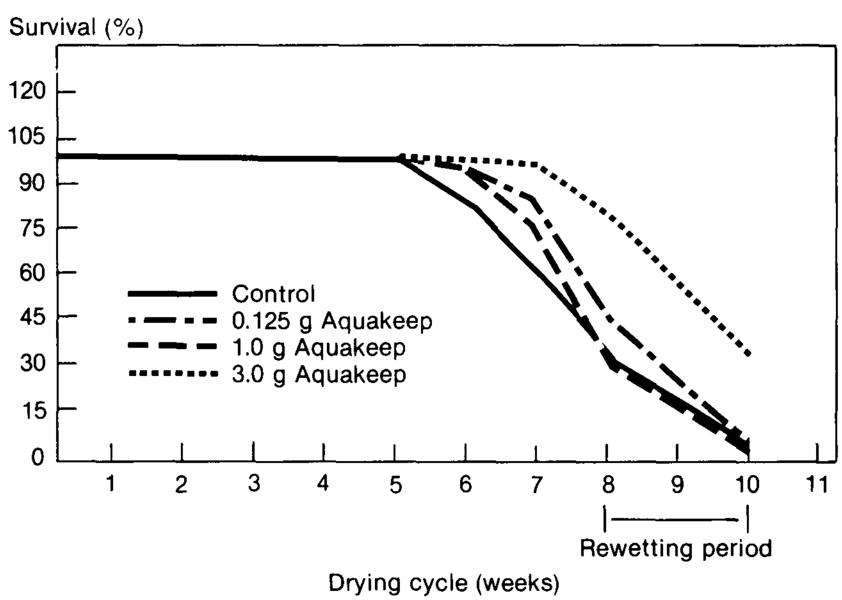

Figure 2—*Weekly mean survival for Douglas-fir container seedlings treated with Aquakeep during an 8-week drying cycle*

The 3.0-gram treatment exhibited a much smoother moisture stress and survival response curve. This may be attributed to the fact that this was the only treatment in which the wetting agent remained wet for the duration of the drying cycle. The major problem with the 3.0-gram treatment was a physical limitation. Apparently, for our potting mix and planting stock, this quantity of wetting agent was excessive. Expansion of the wetting agent as it absorbed water resulted in the plugs being pushed from the planting medium. Plugs were reinserted and the excess wetting agent remained on the surface of the planting medium. Plugs did not come out after reinsertion.

Although the treatments resulted in differential mortalities, the seedlings were responding to moisture stress consistently within treatments (fig. 3). The closeness of the fit in this mortality function suggests a strong link between accumulated moisture stress and seedling mortality. Unfortunately, due to the limitations of our pressure bomb (i.e., maximum 40 bars), we were unable to develop a "moisture stress day" relationship with mortality. Our results indicate this would be a fruitful avenue of future research.

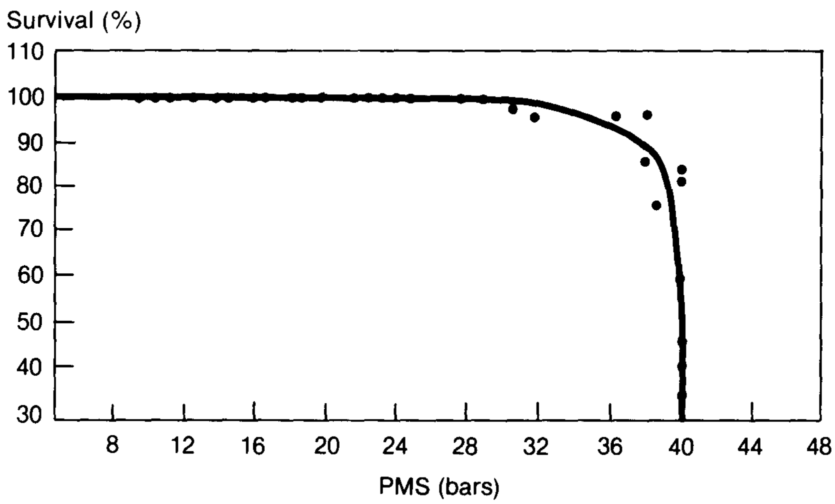

Figure 3—*Relationship of moisture stress and survival for Douglas-fir container seedlings*

Conclusions

The results of this experiment indicate that use of a wetting agent (*Aquakeep*) can provide significant relief of moisture stress and reduce mortality for Douglas-fir plug planting stock during prolonged periods of drought. Up to 3.0 grams of wetting agent per seedling can be effective. However, levels need to be field tested to determine acceptable upper limits. Operational field tests will be necessary to determine the most cost-effective means of delivery and the types of sites most likely to benefit.

Three-year Survival and Height Growth of 2+0 Bareroot Douglas-Fir Seedlings Treated with a Symbex Root Dip

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Douglas-fir 2+0 bareroot seedlings root-dipped in Symbex prior to planting showed no significant differences in height or survival benefits from controls in a 3-year test. The first-season height growth differences were significant and favored the root dip treatment, but this effect did not persist.

Douglas-fir (*Pseudotsuga menziesii*) plantation survival and growth on the east side of Vancouver Island, BC, is primarily influenced by the seedling's ability to rapidly develop an effective root system in a large soil volume prior to the onset of summer drought (4). Plants unable to do this either die due to excessive moisture stress or are unable to elongate stem units, resulting in slow plantation growth (2,3,6).

One means of stimulating root system development after planting may be to provide fertilizer (1) and root-stimulating microorganisms at the time of planting (5). Agrok Corporation has developed an agricultural product (Symbex) that has shown significant growth and yield benefits, both as a seed innoculant and as a seedling-root dip treatment in agricultural crops. The objective of the following trial was to determine if similar gains could be shown on 2-year-old bareroot Douglas-fir planting stock on a stressful site on Vancouver Island.

Methods

This experiment was designed as a randomized block with two treatments (dip in Symbex or dip in water), three replicates, and 25 seedling-rows per treatment per replicate. The seedlings were 2+0 barefoot Douglas-fir (*Pseudotsuga menziesii* (Mirb). Franco) grown from one seedlot in a single nursery. The Symbex treatment consisted of dipping the seedlings five times (approximately 5 seconds each time) in a solution of Symbex diluted 40:1 with water. Control seedlings were similarly dipped in water prior to planting. Seedlings were assessed at the end of each growing season for survival and height growth.

The planting site was a well-drained, coarse-textured alluvial soil with a Douglas-fir site index at 50 years of approximately 18 meters. Seedlings were planted May 12, 1980, and were untended for the 3-year course of this study.

Results and Discussion

The results indicate that there were no significant differences ($P >= 0.05$) in total height, height growth, or survival between treated and untreated seedlings over the 3-year duration of the test (table 1, fig. 1). A height growth advantage (approximately 20 percent) for the treated plots did become evident during the 1981 growing season. However, this result did not persist and the control trees began to close the gap during the 1982 season. The total height gain on the average over the three growing seasons was 4 centimeters or approximately 6 percent in favor of the Symbex-treated trees. The material and labor costs required to do this treatment on an operational basis would not make the Symbex cost-effective.

Table 1—*Total height and survival results for treated and untreated plots, 1980–1982 growing seasons*

	1980		1981		1982	
Treatment	Height (cm)	Survival (%)	Height (cm)	Survival (%)	Height (cm)	Survival (%)
Control	36.9	100.0	52.4	96.4	69.5	94.6
Symbex	37.2	98.1	56.1	92.2	73.6	92.0

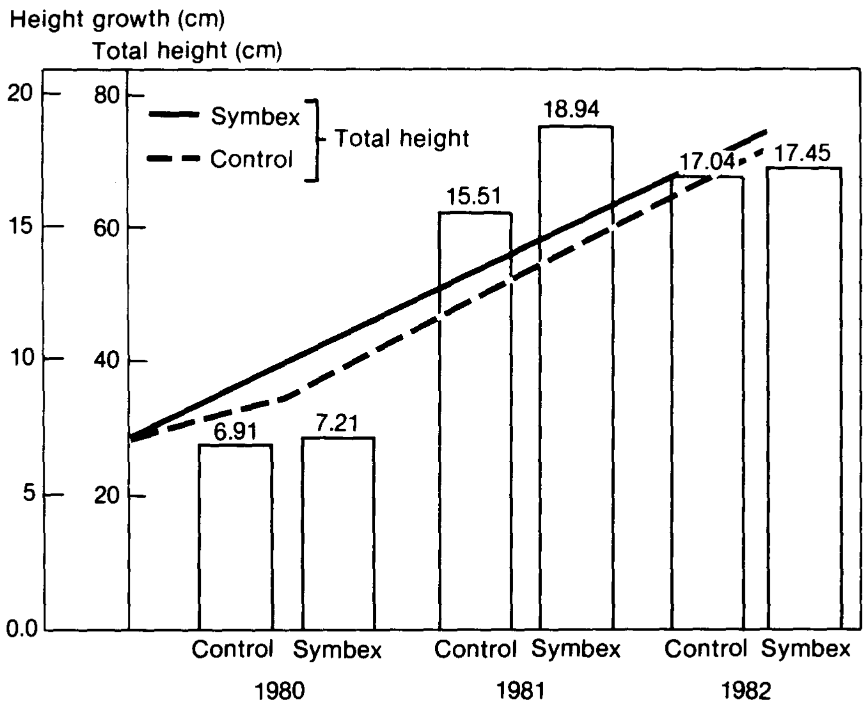

Figure 1—*Height growth and total height of 2 + 0 bareroot Douglas-fir seedlings planted in a stressful site on Vancouver Island.*

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Applying Herbicides with a Modified Automatic Drench Syringe

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Modifications of an automatic drench syringe herbicide applicator to vary spray patterns are described. When used to release established conifers from grass and low shrub competition, this "Spotgun" was faster, less fatiguing, and more versatile than other commonly used systems.

Spot application of herbicides to small areas as part of site preparation has proven effective in the northern Rocky Mountains. Four-foot by four-foot tree-centered spots treated with a suitable herbicide have provided control of herbaceous vegetation and have substantially enhanced both the survival and growth of planted conifers. With the most effective (and often most expensive) herbicides, spot application is definitely less costly than aerial broadcast treatment. In addition, spot application may reduce the hazards of post-treatment erosion and the invasion of noxious weeds.

Until recently, equipment for spot application has been limited to backpack wand or boom applicators, spinning disk applicators, or wick-type applicators, each with their unique advantages and disadvantages. Recently, an automatic drench syringe, used by veterinarians and stockmen for administering animal medications, was marketed for herbicide application[1] (fig. 1). This "Spotgun," and many of the other automatic drench syringes available from veterinary supply companies, ejects fluid material as a solid stream. It applies a metered amount of liquid with each pull of the trigger and refills the metered chamber (fig. 2) from a small backpack reservoir (figs. 1 and 3).

The type of equipment can easily be modified to deliver a variety of spray patterns. As such, it is a versatile and moderately priced tool for applying herbicides before and after planting. The system has many advantages over other available applicators: it a) allows control of application rate, b) requires no pump or battery power, and c) gives the operator a free hand for shielding trees during post-planting application or for marking treated spots before planting. Also, low maintenance is anticipated.

[1]Forestry Suppliers, Jackson, MS.

Figure 1—*Worker applying herbicide with the modified Spotgun around a tree protected with an improvised shield.*

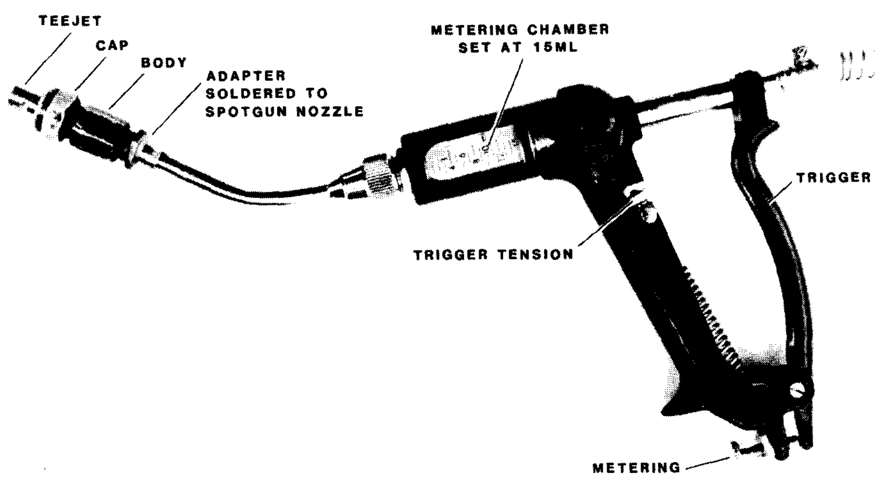

Figure 2—*The Spotgun applicator with the nozzle head modification.*

Modifications and Use

A Spraying Systems[2] TKSS 2 Tee Jet Assembly was silver-soldered to the blunt-pointed head of the Spotgun (fig. 2). A variety of Spraying Systems TKSS 2 Tee Jets can be used. A TKSS 2 Tee Jet provides a 4-foot- to 5-foot-wide, fan-type swath pattern (when held 2 to 3 feet above the spray area) that works well. A side-cast spray pattern can be obtained with a suitable Tee Jet $^{1}/_{4}$ -inch NPT off-center nozzle. With practice, the operator can learn the proper trigger pressure, position above targeted vegetation, and timing to apply a calculated metered amount to the desired area. Practicing with water on dry pavement helps to develop the skills needed.

Extending the delivery tube by about 1 foot would minimize the chances of operators spraying their own feet or lower legs.

For preplanting application, the gun can be held behind the applicator and operated in coordination with the operator's natural pace to achieve the desired spacing of treated spots. On gentle terrain, with few obstacles, a rhythm can be achieved that permits treatment at normal walking speed. Should marking spots with paint be necessary for guiding the tree planter, the operator can use an aerosol can or a paint gun to mark the center of the spot to be treated (fig. 3).

When herbicides to which the trees are not tolerant are applied postplanting, trees can be shielded as shown in figure 1. A shield can be made from a suitably sized can attached to a 3- to 4-foot handle. The shield should be left over the tree until fine droplets settle.

For spraying in front of or to the side of the operator, the bent delivery tube can be positioned as in figure 2. When it is desirable to spray behind the operator, it is more comfortable to mount the tube so that the bend is in the opposite direction. The bent delivery tube is preferred to the straight tube for these types of application.

Figure 3—*Worker applying paint spot before applying herbicide with the modified Spotgun.*

[2] Wheaton, IL (parts available from most agricultural supply outlets).

Comparison with Other Methods

In a recent effort to release established lodgepole pine from severe grass and small shrub competition, four methods of application were tested. Glyphosate (Roundup) was applied around the trees with (a) the modified Spotgun, (b) a pressurized backpack wand applicator, (c) the spinning disk applicator, and (d) a wick-type applicator. Four workers were employed, each treating 60 to 230 trees with each of the applicators. Trees were shielded from herbicide spray with 3-pound coffee cans mounted on the end of a 4-foot-long piece of aluminum conduit. The time required for each worker to treat a group of trees was recorded and converted to time per tree. In addition, each worker was asked to rate each method of application as to ease of operation, speed, and fatigue potential.

In all respects, the modified Spotgun was rated higher than the other application systems. On the average, workers spent 28 percent less time per tree treating with the Spotgun than with other applicators. Workers rated the Spotgun the easiest to handle, the least fatiguing, and the fastest.

Soil Solar Heating for Control of Damping-Off Fungi and Weeds at the Colorado State Forest Service Nursery

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*Solar heating with a 2-mil clear polyethylene covering for 55 days beginning in early July resulted in significant (P < 0.05) reductions in damping-off fungi-*Pythium *spp. (reduced 60 percent) and* Fusarium *spp. (reduced 74 percent) and in weed cover (reduced 97 percent).*

Soil-borne pests such as weeds and damping-off fungi often cause significant seedling losses in forest tree nurseries. Chemical fumigation of the soil is the best control method at present because fungal pathogens and weeds are eradicated in a single application (5). Although soil fumigation in forest nurseries is cost effective (14), many kinds of desirable organisms such as mycorrhizal fungi are also destroyed (18). In addition, fumigation chemicals are hazardous, requiring special handling and disposal procedures. A less expensive and less hazardous method for soil-borne pest control is solar heating. Solar heating of soil (also referred to as solarization or solar pasteurization) is a recently developed technique in which moist soil is covered with a clear polyethylene tarp for several weeks during the hottest part of the growing season (13).

In some locations, application of polyethylene film allows solar radiation to increase soil temperatures to over 40 °C at a 30-centimeter depth (20), chiefly by eliminating evaporation and partly by the greenhouse effect (15). Continuous or repeated sub-lethal temperatures under moist conditions over long periods either kill pathogenic fungi directly or weaken them so they cannot compete effectively with soil saprophytes. Plant pathogenic fungi are apparently more sensitive to elevated temperatures than are saprophytes. Mycorrhizal fungi can survive solar heating and colonize crop roots (20). Solar heating of soil alters the balance of microorganisms to the detriment of plant pathogens, and thus solar heating can be considered an integrated pest management technique (11).

Solar heating has been effective against a variety of pathogens. The fungi *Verticillium dahliae* Kleb., *Fusarium oxysporum* Schlecht., *Rhizoctonia solani* Kuehn, and *Pythium* spp., and the nematodes *Pratylenchus thornei* Sher & Allen and *Ditylenchus* sp. have been controlled on a variety of agricultural crops through solar heating (1, 6, 13, 20, 22). Disease reduction was still evident the second growing season after solar heating. Annual weeds, the parasitic herb broomrape (*Orobanche* spp.), and many perennial weeds have also been greatly reduced (9, 10).

In addition to pest control, solar heating has other beneficial effects. It affects the soil chemistry; increased levels of nitrate and ammonium nitrogen, potassium, calcium, magnesium, chloride, and phosphate in the soil solution have been reported (2, 23). The disease reduction and the increase in soluble minerals both contribute to the increased growth response observed in crops grown in solar heated soil.

Soil solar heating in conifer nurseries has been evaluated recently in a few areas of the United States. Preliminary results at the Iowa State Nursery indicated some reduction in populations of *Fusarium* sp. and soil nematodes from solar heating (4). In trials at the Bend Forest Nursery in eastern Oregon, *Fusarium* sp. population levels were reduced an average of 32 percent due to solar heating, but tree seedling survival after 10 weeks was similar in control and solar heated plots (3). In Wisconsin, no significant reductions in populations of *F. oxysporum, R. solani*, or *Cylindrocladium floridanum* Sobers & Seymour were achieved through solar heating (24). In a northern California nursery near Placerville, *F. oxysporum* was eliminated in soil at and above 10 centimeters depth, and reduced in soil between 10 and 20 centimeters, while *Macrophomina phaseolina* (Tassi) Goid. survived at all depths after solar heating (16).

Solar heating trials were undertaken to assess the effectiveness of the technique in controlling damping-off fungi and weeds at a conifer nursery in the Rocky Mountain Region, the Colorado State Forest Service (CSFS) Nursery, located on the western edge of Fort Collins, Larimer County, CO, at 1561 meters (5120 feet) elevation. The study area soil was sandy clay loam (52 percent sand, 25 percent silt, and 23 percent clay) mapped as Altvan sandy loam in the Kim loam series by the Larimer County Soil Survey (17). Tree seedling production began at the nursery in the middle 1960's.

Study plots were set up in a nursery block in which an entire spruce planting had been recent plowed under because of excessive losses to damping off. The nursery block is 91 by 61 meters (300 by 200 feet), slopes gently (1 to 3 percent) to the southeast, and has never been fumigated.

Materials and Methods

Six plots, 3.7 by 61 meters (12 by 200 feet), were arranged in a randomized block design parallel with nursery beds. Three plots were covered with 2-mil polyethylene film for solar heating (fig. 1), and three plots were left untreated as controls. Buffer strips were left between treatment plots and between the edge of the block and the plots. The block was disked and harrowed in June 1982, and all plots

Figure 1—*Polyethylene tarp in place on a solar heating plot in early July 1982 at the Colorado State Forest Service Nursery.*

were established June 30. After irrigation to field capacity, tarps were placed on solar plots on July 2, anchored at the edges with soil, and removed after 55 days.

Six Peabody Ryan model J thermographs were buried before the plots were covered with polyethylene. One thermo graph was buried at 8 centimeters and one at 15 centimeters along the center of each of two solar and one control plot at a random distance from the ends. The thermograph for the 8 centimeter depth in the control plot was not buried until July 12 because of equipment malfunction.

Soil samples for laboratory assay of populations of damping-off fungi and viable weeds were taken in late June before solar heating, in late August after the tarps were removed, and the following April. Four soil samples (composites of six 15-centimeter soil-probe cores taken in a 30-centimeter radius) were collected at 12-meter intervals along the center of each of the six plots, the first sample spot being chosen at random. Soil samples were assayed as previously described for *Pythium* spp. (7) and *Fusarium* spp. (19).

Analyses of covariance were performed and minimum significant ranges for the means were computed by Tukey's honestly significant difference meth od (21) for population levels of *Pythium* spp. and *Fusarium* spp. For comparison purposes, population levels of *Pythium* spp. of less than 10 propagules per gram of soil were considered low, 10 to 40 moderate, and over 40 propagules per gram high. Population levels of *Fusarium* spp. of less than 1000 were considered low, 1000 to 4000 moderate, and over 4000 propagules per gram high.

Soil for weed tests was collected from the top 2.5 centimeters of soil from within a 929-square-centimeter frame placed at 12-meter intervals (four per plot) for each of the six plots. Soil was poured in aluminum foil pans, watered, and kept in a Scherer Environmental Chamber at 12 hours of light at 25 °C and 12 hours of dark at 18 °C. After 2 weeks, weed seedings were counted. Minimum significant ranges for the means of weed seed germination counts were computed by Tukey's method. For each weed soil sample taken in August (after solar heating), the percent of the area within the frame shaded by the weed canopy was visually estimated and recorded as percent weed cover. Significant differences in percent weed cover were determined by analysis of variance.

Results

Solar heating resulted in a significant ($P < 0.05$) decrease in population levels of *Pythium* spp. and *Fusarium* spp., and in numbers of germinated weed seedlings. Although fungal population levels were quite variable within plots, the effect of solar heating was still significant.

Analysis of covariance between values for control and for solar heated plots in August adjusted by the June (before solar heating) values as covariates showed a significant ($P < 0.01$) difference in population levels of *Pythium* spp. (table 1). Population levels of *Pythium* spp. dropped significantly ($P < 0.01$), an average of 60 percent, due to solar heating from June to August, whereas control plot levels remained high (fig. 2A). In samples from the following spring (April 1983), *Pythium* spp. levels had decreased over the winter in all plots-levels in check plots fell from high to moderate, while levels in solar plots fell from moderate to low.

Minimum significant ranges computed for the means of population levels of *Fusarium* spp. showed a significant ($P < 0.05$) reduction due to solar heating from June to August (fig. 2B), whereas control plot levels did not. Population levels of *Fusarium* spp. dropped an average of 74 percent, from moderate to low, due to solar heating. Between August and the following April, *Fusarium* spp. population levels increased in all plots, but although levels in control plots increased from moderate to high, levels in solar plots remained low. The major pathogenic species encountered were *F. oxysporum* and *F. solani* (Mart.) Sacc.

By August most of the weed seeds in the control plots had germinated and matured, and a new crop of weed seeds was accumulating on the ground. The major weed species growing in the control plots and adjacent areas were purslane (*Portulaca oleracea* L.), clammy groundcherry (*Physalis heterophylla* Nees), and redroot pigweed (*Amaranthus retroflexus* L.). Few weeds grew under the solar tarps,

Table 1—*Analysis of covariance table for propagules per gram of soil of* Pythium *spp. in control and solar-heated plots (August values) adjusted by pretreatment (June) values as covariates*

Source of variation	Sum of squares	df	Mean square	F
Covariates	1423.4	1	1423.4	2.20
Solar heating effect	7360.3	1	7360.3	11.35**
Within group error	13617.0	21	648.4	
Total	22400.7	23		

**Significant at $P < 0.01$.

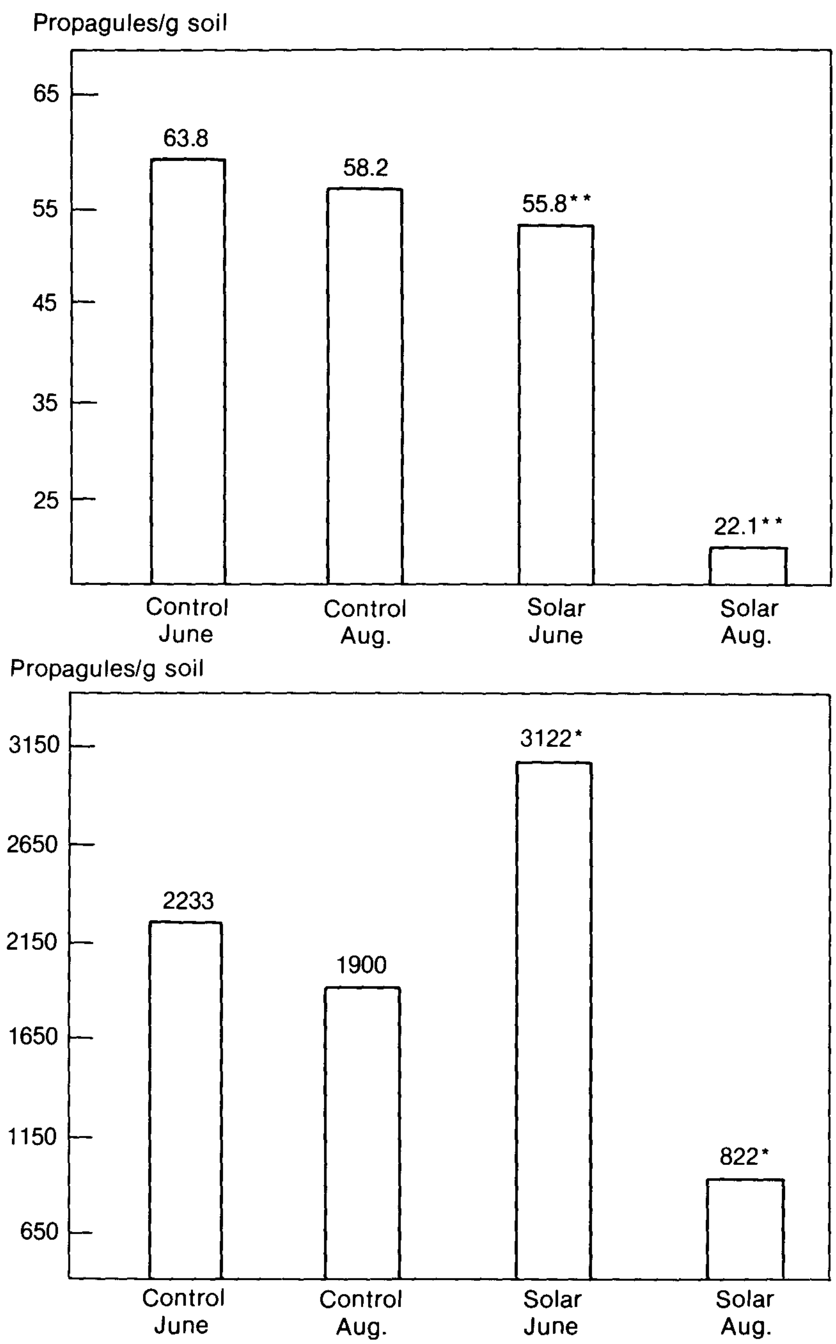

Figure 2—*Effect of solar heating on fungi (average propagules per gram of soil) at the Colorado State Forest Service Nursery.* **A (top)**—*Significant ($P<0.01$) effect on* Pythium *spp.* **B (bottom)**—*Significant ($P<0.05$) effect on* Fusarium *spp.*

although some purslane was growing slowly in spots (fig. 3). Some dead weed seedlings were noticed when tarps were removed. Weed cover in solar plots averaged 97 percent less than in control plots. Minimum significant ranges computed for the means of weed germination counts showed significant ($P < 0.05$) reductions due to solar heating when comparing the June and August solar plot values (fig. 4).

Occasionally, holes in the polyethylene tarps, caused mostly by deer stepping on them to drink from puddles on the surface, required mending. Thick clear-plastic tape was effective. The tarps remained essentially intact until August 23 (after 54 days) when high winds shredded the by-then-brittle plastic.

Surface temperatures of soil averaged 9 °C higher under the tarps than in control plots; at 15 centimeters, temperatures exceeded 41 °C under the tarps. The average high temperature under the tarps at 8 centimeters was 39.6 °C and at 15 centimeters, 34.7 °C. The values are actually higher for solar heated plots, because temperatures exceeding the recording range of the thermograph (10 to 40 °C) were calculated as 41 °C. In control plots, the highest temperature recorded by the 15-centimeter-deep thermograph was 34.2 °C, and by the 8-centimeter-deep thermograph, 38.5 °C. The average high temperature in control plots at 8 centimeters was 28.2 °C and at 15 centimeters, 27.1 °C.

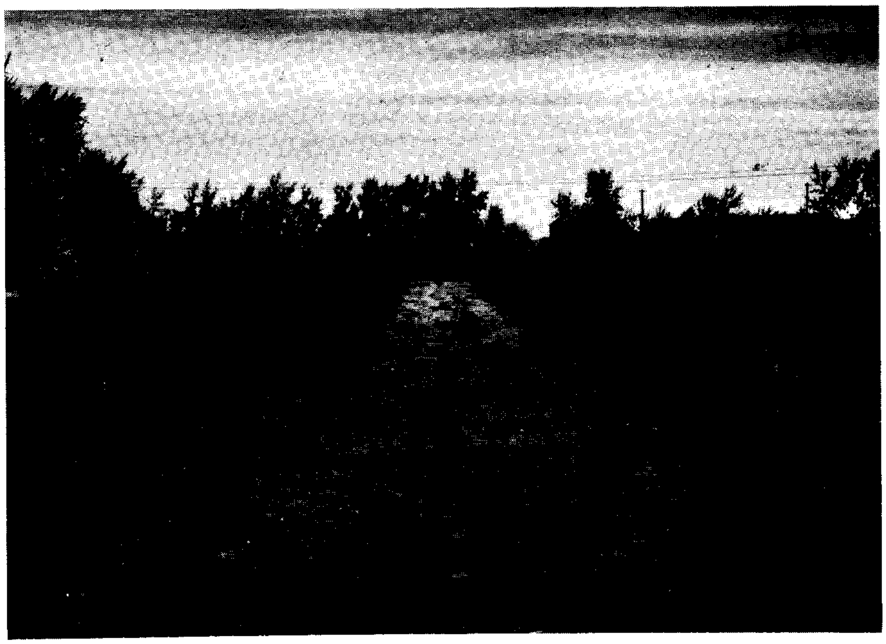

Figure 3—*Solar heated plot in late August 1982 after polyethylene tarp was removed at the Colorado State Forest Service Nursery.*

Temperatures were highly variable from day to day between thermographs at the same depth under solar tarps. Under the solar tarps the 15-centimeter-deep thermographs did not register temperatures greater than 41 °C until late in the third week, whereas readings on the 8-centimeter-deep thermographs exceeded 41 °C on the first day. July temperatures did not differ appreciably from those achieved in August in solar plots. However, for control plots, the August highs averaged several degrees lower than those in July, probably due to shading by weeds.

Discussion

Results in the solar plots show that solar heating of the soil can be effective in reducing populations of damping-off fungi and weeds at a high-elevation Colorado nursery. Weed populations would not become reestablished by the following spring if the entire block were covered with tarp for solar heating and adjacent areas were periodically mown or disked. Population levels of fungal pathogens were significantly reduced, on the average, by solar heating, although the extent of control and the temperatures achieved were quite variable within the plots. The fungal assay as used in this evaluation might give inflated counts because weakened propagules, which may give rise to a colony in the assay but might not survive under field conditions (12), are counted.

In the present evaluation, the soil gradually became drier as weeks passed and was fairly dry by late August, but it probably was sufficiently moist for effective solar heating under the tarps for the first 5 or 6 weeks (6). In addition, the soil was not in the best of tilth. The surface was cloddy and irregular, which increased the size and frequency of air pockets and shadows and may have contributed to the variation in temperatures achieved. Better soil preparation might afford less variation in fungal pathogen control.

Both solar heating and chemical fumigation require favorable weather and the same use of tractor, personnel, tarps, and rollers. With solar heating the safety hazards and cost of handling the toxic fumigant are eliminated. The cost-savings on the price of the fumigant is conservatively estimated at $350 per acre (8). A disadvantage of solar heating is the attention required from nursery personnel to prevent and repair any damage to the tarps during the treatment period. In addition, solar heating requires that the land being treated is taken out of production for the summer before planting.

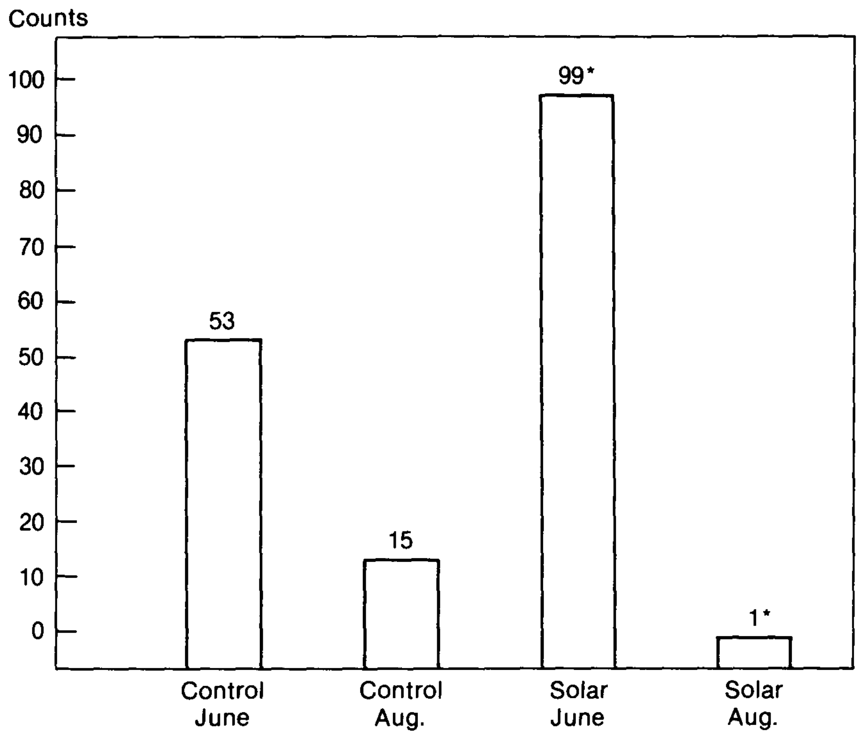

Figure 4—*Average counts of germinated weeds at the Colorado State Forest Service Nursery (1982).*

The ultimate test of the effectiveness of soil solar heating is, of course, survival of planted trees. A spring planting of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) was planned for this evaluation to reveal the effect of residual fungal populations, but weather and nursery problems delayed planting in the study area until too late in the season for any meaningful seedling mortality information. Based on laboratory tests, the good control of weeds and the degree of control of soilborne fungal pathogens afforded by soil solar heating makes the technique a useful alternative, especially where fumigation is not accepted or cannot be used.

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