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Cone Storage and Seed Quality in Eastern White Pine (*Pinus strobus* L.)

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*To achieve maximum seed extraction and germination from stored, immature cones of eastern white pine (*Pinus strobus *L.) the cones should be stored for about 1 week, or until cone moisture drops below 50 percent. Indoor and outdoor storage in burlap bags yielded similar results.* Tree Planters' Notes 37(4):3-6; 1986.

Deciding when to collect and how to handle the cones of eastern white pine (*Pinus strobus* L.) has been a problem for many seed managers. Cone color can be used as a maturity index, and if demand for seed is low, it is possible to delay the collection until cones are a "straw yellow" color (6). The increasing demand for white pine seed in the last 15 years, however, negates the use of cone color, because delaying collection until this color change occurs does not allow enough time to collect large quantities of cones before most of the seeds are disseminated. The best alternative is to use cone moisture content, estimated by specific gravity, as a maturity index. One study in Michigan showed that seeds were mature when cone specific gravities were in the 0.92 to 0.97 range (5). However, cones picked with this much moisture must be handled carefully to avoid severe molding and case-hardening.

Preliminary tests at our laboratory in 1983 showed that green cones from North Carolina averaged 64 percent moisture 1 day after picking and were hard to open in ovens; germination was also poor (3). Storing cones for up to 8 days before ovendrying improved cone opening and seed quality considerably. This test had used indoor storage only; a larger test was installed in 1984 to include outdoor cone storage.

Materials and Methods

Immature cones were collected from 5 to 10 trees in western North Carolina on August 11 and 12, 1984, by a contractor and delivered to the Forestry Sciences Laboratory at Starkville, MI, the following day. The cones were mixed, and two 5-cone samples were immediately taken to determine initial cone moisture content.

The remaining cones were placed in small burlap bags for storage under the following conditions:

(1) outdoors without protection,
(2) outdoors with overhead cover, but exposed to blowing rains, and
(3) inside small, unheated sheds or buildings with complete protection.

There were four replications of each storage condition. Cones stored outdoors (condition 1) were sprayed with hoses every other day to stimulate occasional rainfall when natural rainfall did not occur.

After 2, 5, 8, and 12 days of storage, 20-cone samples were removed from each bag. Five cones were used for determination of specific gravity and cone moisture and five cones were dried at each of three extraction temperatures (30, 35, and 40 °C) in forced-draft ovens.

The cones were dried in trays for 48 hours, then hit against a table top to remove the easily extracted seeds. The cones were then carefully torn apart by hand to recover all other seeds. The number of easily extracted seeds was expressed as a percentage of the total seeds for a measure of extraction efficiency.

The seeds were dewinged by hand, and germination was tested under standard conditions (1) following 56 days of stratification at 3 °C. The percentage of germination was based on filled seeds only. Analyses of variance were carried out using arcsine transformations of extraction efficiency and percent normal germination, and germination rate was expressed by peak value (4). Differences among means were tested by Duncan's new multiple range test. All tests of significance were made at the 95 per-

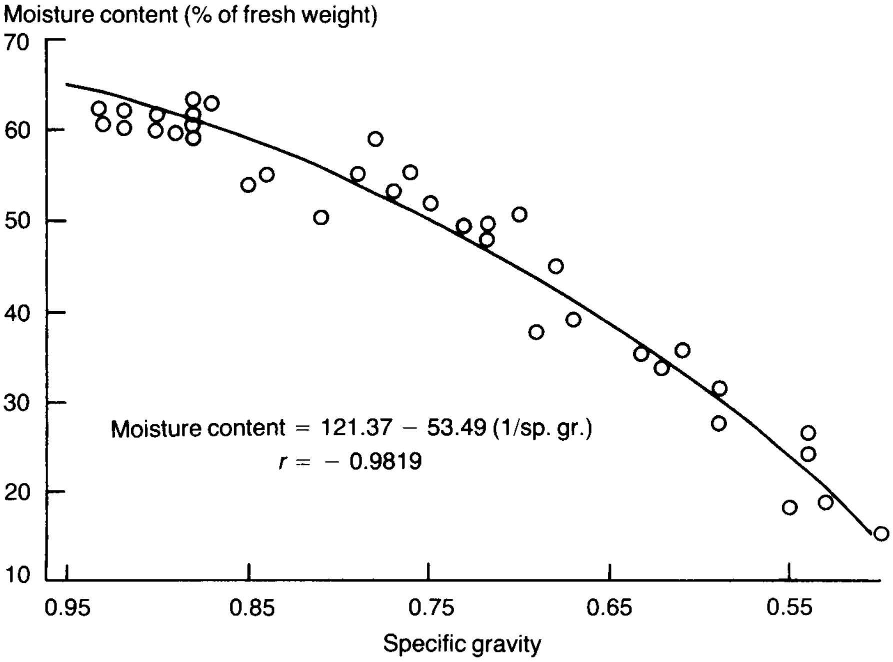

Figure 1—*The relationship of specific gravity to moisture content in cones of eastern white pine.*

Table 1—*Moisture content of cones stored for 2 to 12 days under three conditions (all percentages are based on fresh weight)*

Storage condition	Average moisture content (%)				
	0 days	2 days	5 days	8 days	12 days
Outdoors	62.2	61.2	52.2	48.1	17.6
Outdoors, covered	62.2	60.5	49.7	38.5	12.3
Indoors	62.2	61.0	55.4	36.7	26.0

cent level of confidence.

The specific gravity of cones was measured by water displacement (2). Moisture contents were determined by weight loss of cones dried for 24 hours at 105 °C and were expressed as a percentage of fresh weight. Each of these cones was cut into three or four pieces with a cone cutter for the determinations.

Results and Discussions

Cone Moisture. The initial cone moisture content averaged 62.2 percent. The cones still had their green, vegetative color, and they did not open when placed in the drying ovens. The initial specific gravity of the cones was not measured, but it can be estimated as about 0.90 based on the relationship of specific gravity and cone moisture that was established with measurements taken during the storage test (fig. 1). The strong correlation between the two (r = 0.9819) illustrates how well moisture content can be estimated by specific gravity in eastern white pine cones.

During the storage period, cone moisture loss was about equal under all conditions for storage periods of 2 and 5 days (table 1). Rain on the seventh day kept outdoor cones high in moisture, but they lost moisture rapidly after that time. At 12 days, cones stored indoors had the highest moisture, 26.0 percent, while cones from the outdoor conditions had moisture levels of 17.6 and 12.3 percent.

Extraction Efficiency. Neither storage condition nor drying temperature had any significant effect on extraction efficiency (table 2); however, length of the storage period was very important. Extraction removed an average of only 13 percent of the total seeds after 2 days of storage and was best at 8 days (69 percent). The best extraction efficiency was

Table 2—*Extraction efficiency for cones of white pine stored for 2 to 12 days under different conditions and dried at three temperatures*[1]

Temperature (°C)	Extraction efficiency (%) 2 days	5 days	8 days	12 days	Mean
Outdoor storage					
30	18	41	35	61	38
35	35	61	86	56	60
40	26	41	87	63	55
Mean	26	48	71	60	51
Outdoor storage, covered					
30	1	34	72	62	38
35	7	55	76	44	44
40	11	65	72	41	46
Mean	6	51	73	49	43
Indoor storage					
30	12	60	59	69	49
35	18	56	66	64	51
40	5	63	65	66	47
Mean	11	60	63	66	49
Means[1]	13a	53b	69c	58b	

[1] Means followed by the same letter do not differ significantly ($P > 0.05$).

obtained after 8 days of storage (table 2), when cone moisture contents had fallen below 50 percent (table 1). Similar results had been obtained in the 1983 test (3).

Cones allowed to dry to below 20 percent moisture while in storage did not open as well when heat was applied and had extraction efficiencies of only 60 and 49 percent, similar to values obtained in the 1983 test.

Germination. As with extraction efficiency, percentage total germination was not affected by the storage conditions but was significantly affected by the length of storage (table 3). Seed from cones stored only 2 days before extraction had significantly lower total germination than seed from cones stored for longer periods. The highest mean total germination was 75 percent after 8 days of storage, but it was not significantly better than the values for 5 to 12 days of storage.

Extraction temperature also had a significant effect. Seed from cones dried at 30 °C averaged only 56 percent of percentage total germination, whereas seed extracted at 35 °C averaged 77 percent. Germination of seed extracted at 40 °C was only 65 percent, significantly lower than the 77 percent at 35 °C.

Germination expressed as peak value (PV), the maximum cumulative percentage germination divided by the number of days from sowing (4), followed the pattern of percentage total germination. Seed from cones stored only 2 days germinated at significantly lower rates than did seed from cones stored longer (table 3). The best extraction temperature was 35 °C; there was no difference between 30 and 40 °C. There was a significant interaction between storage period and extraction temperature; at 30 °C, the quality of extracted seed increased as the storage period increased from 2 to 8 days.

One remaining question is whether or not cone storage will affect the long-term storage potential of seed. Seed from this study are now in a storage test to provide the answer.

Conclusions

The data clearly show that immature white pine cones should be stored for about 1 week before heat is applied to the cones for seed extraction to obtain the best yields and seed quality. In this test, the best extraction rate was obtained after 8 days of storage, although seed quality was just as good from cones stored 5 to 12 days. Both indoor and outdoor storage were equally successful. Cone moisture content appears to be the key factor,

Table 3—*Germination of seeds extracted from cones of white pine stored for 2 to 12 days under different conditions and dried at three temperatures*

Temperature (°C)	2 days	5 days	8 days	12 days	Mean
Total germination (%)					
Outdoor storage					
30	30	55	51	67	51
35	70	85	86	79	80
40	64	52	67	74	72
Mean	54	65	69	73	66
Outdoor storage, covered					
30	12	54	76	62	50
35	71	66	92	73	76
40	42	81	75	57	64
Mean	40	68	82	64	64
Indoor storage					
30	52	74	66	78	68
35	74	79	77	62	73
40	59	75	74	50	65
Mean	62	76	73	64	69
Means[1]	52a	70b	75b	67b	
Peak Value					
Outdoor storage					
30	1.3	2.2	2.0	2.6	2.0
35	2.8	3.4	3.6	3.0	3.2
40	2.8	2.0	2.5	2.9	2.6
Mean	2.3	2.5	2.7	2.9	2.6
Outdoor storage, covered					
30	0.6	2.0	2.8	2.5	2.0
35	2.7	2.4	4.0	2.8	3.0
40	1.6	3.0	2.9	2.1	2.4
Mean	1.6	2.5	3.2	2.5	2.4
Indoor storage					
30	2.2	2.7	2.4	2.8	2.6
35	3.2	2.9	3.1	2.4	2.9
40	2.2	3.0	2.6	1.9	2.4
Mean	2.5	2.9	2.7	2.4	2.6
Means[1]	2.2a	2.6b	2.9b	2.6b	

[1] Means followed by the same letter do not differ significantly ($P > 0.05$).

however. Extraction should not be started until cone moisture drops below 50 percent. If drying conditions during storage are slower than in the current test, this may take longer than 8 days.

The best extraction temperature was 35 °C, and higher temperatures should be used only with great care.

Literature Cited

1. Association of Official Seed Analysts. Rules for testing seeds. Journal of Seed Technology 6(2):1-126; 1981.
2. Barnett, James P. An easy way to measure cone specific gravity. In: Proceedings of seed collection workshop; 1979 May 16-18; Macon, GA. SA-TP-8 Atlanta, GA: U.S. Department of Agriculture, Forest Service, State and Private Forestry; 1979: 21-23.
3. Bonner, F.T. Effects of seed extraction on the quality of southern pine seeds. Proceedings of the 1984 Southern Nursery Conferences; 1984 June 11-14; Alexandria, LA; and July 24-27; Asheville, NC. Atlanta, GA: U.S Department of Agriculture, Forest Service, Southern Region; 1984: 111-120.
4. Czabator, Felix J. Germination value: an index combining speed and completeness of pine seed germination. Forest Science 8:386-396; 1962.
5. Jones, LeRoy; Massello, James W.; Clifford, Edward D. Size and germination of white pine seed collected at weekly intervals from five trees. Res. Note 5E-74. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1967. 6 p.
6. Manchester, Edwin H. Cone harvest of eastern white pine. In: Proceedings of seed collection workshop; 1979 May 16-18; Macon, GA. SA-TP-8 Atlanta, GA: U.S. Department of Agriculture, Forest Service, State and Private Forestry; 1979: 24.

Homemade Potting Mixes for Container Planting in the Pacific Islands

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Locally available soil, sand, paper, and vegetative material were made up into potting mixes and compared with standard mixes of peat moss and vermiculite for suitability in growing Eucalyptus saligna *Sm. and* Casuarina equisetifolia *L. ex J.R. & G. Forst. Mixtures of one part each of grass clippings, soil, and calcareous sand produced good plantable stock of both species. Mixtures containing waste paper,* Leucaena leucocephala *(Lam.) de Wit leaves, and sand and soil without organic material were generally found to be failures for growing* Eucalyptus*, but* Casuarina *grew better in some of these media than in the commonly used peat moss/vermiculite.* Tree Planters' Notes 37(4):12-16; 1986.

Tube-container tree nurseries are becoming popular in some islands of Micronesia. Ideal materials for potting mix in the containers are peat moss and vermiculite. Unfortunately, the shipment of such bulky materials to these islands is prohibitively expensive. Thinking it possible to find some readily available substitute materials on these islands, we tried several soil and vegetative materials of Hawaii that essentially correspond to those in Micronesia. We tested these planting mixes by growing *Eucalyptus saligna* and *Casuarina equisetifolia* L. ex).R. & G. Forst, both of which grow on some islands in Micronesia.

Potting mixes for tube-shaped containers must have suitable characteristics. Most importantly, they must remain soft and deformable so that the seedling can be removed from its container once it is grown. Tubes filled with sand or soil cannot be deformed by squeezing once the roots have filled the original voids in the medium, preventing the plants from being removed without serious breakage. The material must also provide rapid drainage, have a pH in the range suitable for the plants to be grown, and have a high cation exchange capacity. Ideally, the material should also be lightweight so that racks of containers and seedlings can be moved and handled easily.

Most tropical Pacific Islands have abundant coral ($CaC0_3$) sand and soils formed from calcareous rock. Many also have soils formed from basic igneous rock. The Mariana Islands, in particular, have extensive stands of *Leucaena leucocephala* (Lam.) de Wit, a weedy shrub or small tree that has lately become popular for fuelwood plantings. These islands also have scattered grass lawns, often near nursery sites, and abundant waste paper. Therefore, we selected the following materials for our trial potting mixes: sand, soil, leaves, grass clippings, and small bits of paper.

Methods

The materials selected for trial were beach sand, lowland soil, upland soil, *Leucaena* leaflets, lawn grass clippings, and confetti (to simulate finely cut waste paper). The beach sand, a mixture of shell and coral fragments, was essentially pure $CaC0_3$ with a pH of 8.4. It was washed to remove salt before use. The lowland soil was Waialua clay, an agricultural soil formed in place on an old coastline coral shelf with some igneous alluvium inclusions. The sample used had a pH of 6.2. The upland soil was Papaa clay, a reddish-brown oxisol formed on old basalt. The sample used had a pH of 4.4.

The sand and soils were fumigated with Dowfume (a restricted use fumigant requiring a licensed applicator) before mixing. The *Leucaena* leaflets, which are about 0.5 by 1 centimeter in size, were stripped from trees near the nursery and air dried. The grass clippings from a nearby Bermuda grass ('Sun Turf') lawn were used fresh. The confetti was circular bits of magazine paper about 0.5 centimeter in diameter. It had clay coating and ink typical of waste paper of this type.

The constituents were mixed by hand using parts by volume, each part consisting of a loosely packed 500-milliliter beaker. The potting mixes were placed in tube-shaped polyethylene containers of the size and shape developed for use in Hawaii (1). Two experiments were carried out at different seasons, each with the same control potting mix (2 parts peat moss, 1 part vermiculite), but with different treatments. Treatments were as follows:

Experiment 1
(cool season)

1. Peat moss (2 parts), vermiculite (1 part)—control
2. Leucaena leaves (2 parts), Waialua soil (1 part)
3. Leucaena leaves (2 parts), Papaa soil (1 part)
4. Leucaena leaves (2 parts), Waialua soil (1 part), beach sand (1 part)
5. Leucaena leaves (2 parts), Papaa soil (1 part), beach sand (1 part)
6. Confetti (2 parts), Waialua soil (1 part)

Experiment 2
(warm season)

7. Peat moss (2 parts), vermiculite (1 part)—control
8. Waialua soil (1 part), beach sand (1 part)
9. Papaa soil (1 part), beach sand (1 part)
10. Grass clippings (1 part), Waialua soil (1 part), beach sand (1 part)
11. Grass clippings (1 part), Papaa soil (1 part), beach sand (1 part)

We used 10 replications of each *Eucalyptus* treatment and five of each *Casuarina.* The tubes were completely randomized in one holding rack. The seedlings were grown on a greenhouse bench for 4 months.

During the growing period, seedlings were soaked once daily and fertilized twice weekly with 300 milliliters of a 1:1 mixture of Ortho 10-8-7 in water. The plants were started from a pinch of seed per tube and were thinned to one per tube when it became apparent that the seedling saved would survive. Germination tests were made of 30 seeds of each species on gravel-covered media of the same mixtures in the tubes.

Survival counts and height growth measurements were made monthly. At termination after 4 months' growth, seedlings were photographed, then removed from their containers using-to the extent possible--uniform hand squeezing and pulling procedures. The ease of removal from the tube, the retention of a tube shape by the root mass upon removal, and the compactness of the root mass were comparatively rated for acceptability for planting.

Then, the medium was washed from the roots, and the roots and tops of the plants were measured and weighed. Measurements consisted of total leaf area, total root area, and ovendry weights of tops and roots. The presence and amount of root nodules on *Casuarina* were also noted.

Results and Discussion

Treatments that included *Leucaena* leaves exhibited poor germination after only 3 weeks, more apparently among the *Eucalyptus* than the *Casuarina.* Germination tests were then started in sand alone and in the other media from experiment 1, with sand substituting for the control. In these tests, 30 seeds of each species were placed on each medium. Counts were made after 10, 20, and 30 days (table 1). These separate germination tests were made because a pinch of seed, rather than a known number, had been placed in the tubes.

In the second experiment, germination was satisfactory in tubes. Independent germination tests were therefore not made. However, of the five treatments

Table 1—*Germination percentage of* Eucalyptus saligna *and* Casuarina equisetifolia *sown on sand and other media*

		Germination percentage after sowing					
		10 days		20 days		30 days	
	Treatment	Euc.	Cas.	Euc.	Cas.	Euc.	Cas.
1.	Sand	37	27	43	33	43	33
2.	Leucaena + Waialua	0	7	0	13	0	13
3.	Leucaena + Papaa	0	3	0	3	0	3
4.	Leucaena + Waialua	3	7	3	7	3	7
5.	Leucaena + Papaa	3	10	3	20	3	23
6.	Paper + Waialua	23	17	23	33	23	33

Euc. = *Eucalyptus saligna;* Cas. = *Casuarina equisetifolia.*

in the second test, the two *Eucalyptus* treatments with grass clippings required pricking in of seedlings from other tubes to 4 tubes out of 10 in each treatment in order to obtain 10 replications.

It was apparent that nondecomposed vegetative material reduced and retarded germination. *Leucaena* and grass retarded *Eucalyptus*; *Leucaena* alone retarded both Casuarina and *Eucalyptus*. The effect of *Leucaena is* believed to be caused by phenolic substances formed in the leaves in the early stages of decomposition. Kuo et al. (2) found that extracts of air-dried *Leucaena* leaves inhibited or suppressed radicle growth of several species. In our study, *Eucalyptus* was affected to a greater degree than *Casuarina.* Had we been aware initially of the problem with *Leucaena*, we would have composted the leaves to overcome the problem.

After growing for 4 months, the seedlings were removed from their containers. The tube was first squeezed to deform the root mass and free it from the container walls, then the plant and root mass were pulled out. We tried to do this in as similar a manner as possible for each seedling. The ease of removal and the retention of root mass form after removal were judged on the basis of acceptability for planting and probability of seedling survival. The percentage that was rated acceptable varied for the different treatments (table 2).

The pH of the peat moss-vermiculite mix was quite different between the two experiments (table 2). The reason is unknown because we did not check the pH of the ingredients of the second batch before combining them. Although the first, more-acid peat moss-vermiculite mix was suitable for both species, the second, less-acid batch was not at all suitable for growing *Casuarina.*

All five plants in this second control treatment nodulated well but were significantly lower in dry weight than the plants in the other treatments. The peat moss-vermiculite mix also produced lightweight *Casuarina* plants in the first (cool season) experiment, suggesting that this much-used mix is not well-suited for the species. Both species grew much larger in the second experiment, which was carried out in late summer and fall during very favorable warm weather.

Leucaena leaflets greatly raised the pH of the soils and sand-soil mixes to which they were added. Their addition had an ameliorative effect apparently about equal to that of the pure calcium carbonate sand. Both *Eucalyptus* and *Casuarina* had germinated satisfactorily in this sand.

Poor survival of three of the four *Eucalyptus* treatments containing *Leucaena* leaflets may have influenced statistical comparisons with the control. The plant roots had not grown sufficiently in these mixtures of

Table 2—*Survival, condition, and growth of* Eucalyptus saligna *and* Casuarina equisetifolia *seedlings after 4 months in the potting mixes tested*[1]

Treatment	Initial pH	% Survival	% Acceptable	Height at 4 months (cm)	Leaf area (cm^2)	Dry weight (g)
Eucalyptus saligna						
Experiment 1						
1. Peat + vermiculite	5.4	100	100	13.0 a	41.7 a	0.57 a
2. Leucaena + Waialua	6.3	30	33	8.4 a	34.6 a	.44 ab
3. Leucaena + Papaa	6.0	20	50	8.9 ab	46.8 a	.54 ab
4. Leucaena + Waialua + sand	7.3	30	67	10.6 a	46.6 a	.60 a
5. Leucaena + Papaa + sand	7.2	90	78	12.6 a	58.0 a	.69 a
6. Paper + Waialua	6.5	100	0	3.2 b	1.3 b	.05 b
Experiment 2						
7. Peat + vermiculite	6.3	100	100	25.7 x	95.1 x	1.82 x
8. Sand + Waialua	6.5	100	60	20.2 x	62.7 x	1.42 x
9. Sand + Papaa	6.2	100	100	24.4 x	73.4 x	1.68 x
10. Grass + Waialua + sand	6.9	100	90	26.4 x	95.2 x	1.81 x
11. Grass + Papaa + sand	6.5	100	80	19.8 x	76.0 x	1.39 x
Casuarina equisetifolia						
Experiment 1						
1. Peat + vermiculite	5.4	100	100	14.2 a	8.4 a	0.23 a
2. Leucaena + Waialua	6.3	60	67	9.7 a	7.1 a	.20 a
3. Leucaena + Papaa	6.0	80	50	15.6 a	13.7 a	.44 a
4. Leucaena + Waialua + sand	7.3	100	100	18.8 a	15.1 a	.41 a
5. Leucaena + Papaa + sand	7.2	60	100	16.9 a	14.8 a	.37 a
6. Paper + Waialua	6.5	0	—	—	—	—
Experiment 2						
7. Peat + vermiculite	6.3	100	60	19.1 x	15.6 x	.36 x
8. Sand + Waialua	6.5	100	80	30.0 y	42.1 y	1.02 y
9. Sand + Papaa	6.2	100	80	27.7 xy	37.9 xy	1.02 y
10. Grass + Waialua + sand	6.9	100	100	33.5 y	54.3 y	1.39 y
11. Grass + Papaa + sand	6.5	100	100	31.0 y	49.7 y	1.19 y

[1] Means followed by the same letter in the same species and experiment do not differ significantly at the 5 percent level.

leaves and soil to hold the root mass together, so even the survivors were judged unacceptable for planting. The addition of sand improved the *Leucaena*-soil mixes for use with Eucalyptus, but the plants were hard to remove from the tubes, particularly those with the stickier Waialua soil. Only 3 of 10 plants survived in the *Leucaena-Waialua*-sand mixture, while 9 of 10 did in the mixture with Papaa soil.

As mentioned, germination was reduced by the presence of *Leucaena* leaves and to a lesser extent by grass. It was possible to lift extra seedlings from those tubes containing grass treatments and transplant them into tubes where none germinated, after which they grew well. In *Eucalyptus* and *Casuarina* treatments with poor survival, the losses occurred after germination and resembled damping off. We believe that the poor germination and subsequent mortality could have been avoided had we used decomposed, rather than air-dried, leaves because *Leucaena* leaves are often used in Hawaii for compost without problems of phytotoxicity.

The mix of small bits of paper and Waialua soil was a complete failure with both species. The paper impeded drainage. The medium was always completely saturated, and root growth could not occur except at the surface, where oxygen was available. It is possible that either the ink or the coating on the paper was toxic, but it appeared obvious to us that poor drainage was the primary cause of poor growth because germination of the *Eucalyptus* was unaffected. The roots were too small to hold the mix together when pulled from the tubes.

In the first experiment, the only acceptable *Eucalyptus* treatment other than the control was number 5, *Leucaena* + Papaa + sand, and even that treatment had two failures during removal of plants from the tubes when the medium fell apart.

The results were somewhat better with *Casuarina* (table 2). Both *Leucaena* + soil + sand treatments produced acceptable plants with plantable root systems, although poor survival of treatment 5 indicates that treatment 4 might be the better choice of the two. Curiously, the roots of these two treatments grew in the center of the tubes rather than along the tube walls as they normally do in peat moss + vermiculite.

In the second experiment, all four trial mixes produced acceptable growth in both species (table 2). For *Casuarina,* all trial mixes were much better than the peat moss-vermiculite control, with the grass-soil-sand mixes promoting significantly better height, leaf area, and weight. The sand-soil mixes were very hard and difficult to deform once the roots had filled the tubes, causing plants to break on removal. This was very pronounced with *Eucalyptus* in the sand-Waialua soil mix, but it was possible to obtain complete plants from the sand-Papaa soil mix with considerable extra effort. Because of this difficulty of removal, we consider the grass-soil-sand mixes to be the only ones really acceptable among those tried. Nodulation of *Casuarina*, present to some extent in all treatments, was equally complete in the control and the two grass-soil-sand treatments.

Conclusions

An apparently acceptable potting mix can be made of local materials available on most of the Pacific Islands. Based on the results of this study, we suggest composting any fresh organic material to allow at least partial decomposition before use. Fresh or air-dried *Leucaena* leaves should be avoided. In fact, we suggest avoiding the fresh leaves of any plant that has a sparse or absent understory, which indicates possible allelopathy, a survival mechanism common to many plants.

Mixtures of sand, soil, and grass clippings were acceptable as potting mixes for *Eucalyptus saligna*, and were actually preferable to the peat moss-vermiculite mix commonly used in nurseries in Hawaii for *Casuarina*. Survival and growth in the sand, soil, and grass mix would likely have been better if composted grass had been used.

Literature Cited

1. Walters, G.A. Why Hawaii is changing to the dibble-tube system of forestation. Journal of Forestry 79 (11):743-745; 1981.
2. Kuo, Y.L.; Chou, C.H.; Hu, T.W. Allelopathic potential of *Leucaena leucocephala. Leucaena* Res. Rep. 3:65. Waimanoalo, HI: Nitrogen Fixing Tree Association; 1982.

A Case for Improving the Efficiency of Seed Extraction from Black Spruce (*Picea mariana* (Mill) B.S.P.) Cones

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*Viable seed was obtained from cones of black spruce (*Picea mariana *(Mill.) B.S.P.) through 16 extraction cycles. Although seed quality declined somewhat in later cycles, total yields were well above those commonly reported. Seed yields could be improved appreciably if more efficient extraction processes were developed.* Tree Planters' Notes 37(4) : 7-11; 1986.

The current expansion in black spruce (*Picea mariana* (Mill.) B.S.P.) reforestation programs, in both Canada and the United States, has greatly increased the demand for seed of this species. To meet this demand and to reduce the resultant high costs of cone procurement, efforts have focused on developing more efficient cone harvesting techniques and equipment (10). Little attention has been given to the possibility of augmenting seed yields through refinements in extraction processes.

Average yields from large-scale extraction facilities range from 8 to15 cleaned black spruce seed per cone (4, 8). However, the seed potential-the maximum number of seeds a cone is capable of producing (1)-for this species is generally at least five times higher (6, 7). Yields of more than 30 sound black spruce seeds per cone have been reported (5). Undoubtedly the semi-serotinous nature of the cones makes efficient seed extraction more difficult.

During black spruce cone and seed studies we have invariably found seeds remaining in the cones following extraction (8). In order to remove a large portion of the seeds from newly ripened cones, several extraction cycles have been necessary. This article outlines the effects of repeated soaking, drying, and tumbling cycles on seed yields and seed quality when small lot seed processing equipment is used. It also emphasizes the need to ensure that extraction and cleaning procedures for black spruce are as effective as possible, whether for processing small lots or for bulk quantities in large-scale extractories.

Materials and Methods

Three different September collections of newly ripened cones were used: a 1977 collection of 10 cones from each of 5 trees from a 40-year-old lowland stand east of Sault Ste. Marie, Ontario; a 1979 bulk collection from a 110-year-old upland stand near Thunder Bay, Ontario; and a 1980 bulk collection from a 90-year-old upland stand north of Thunder Bay. The cones from Sault Ste. Marie were stored in Kraft paper bags at room temperature (20 °C) for 3 weeks before processing; those from Thunder Bay were stored at 0.5 °C for 5 months.

Two extraction methods were used. With method A, cones were soaked in 20 to 25 °C water for 30 minutes, drip-dried for 1 hour, heated in a drying oven for 22 hours at 50 °C, and then tumbled for 20 minutes. With method B, which was similar to that suggested by Safford (8), cones were soaked in cold water for 4 hours, dried at room temperature for 20 hours, heated at 60 °C for 8 hours, and then tumbled for 20 minutes. In each case, cones were put through 16 repetitions (extraction cycles) of the particular extraction method(s) employed.

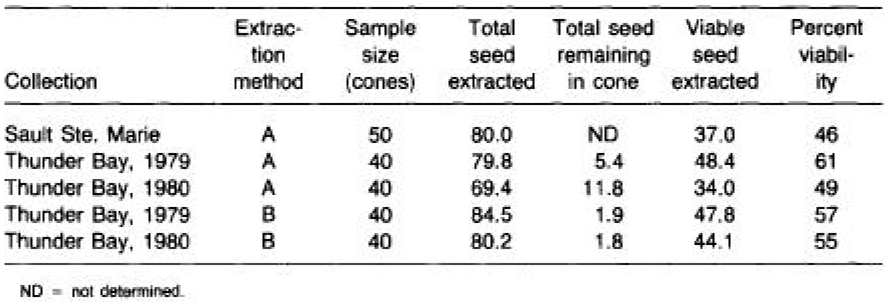
In the first experiment, the Sault Ste. Marie cones were processed separately for each tree by method A, while four 10-cone replicates from each of the Thunder Bay collections were processed by each method. Following the 16 extraction cycles, the Thunder Bay cones were dissected and the number of fully developed seeds (1) remaining was tallied. For each combination of cone collection and extraction method, germination tests were then conducted separately on all seeds recovered from each extraction cycle. Seeds were placed on saturated germination paper overlying bleached Kimpak in covered petri dishes and incubated under continuous low-level incandescent light at a constant 21 °C for 28 days (2). Germination (radicle at least 2 millimeters long) was tallied daily.

In a second experiment conducted to obtain greater quantities of seed for a more thorough investigation of the effects of repeated soaking and tumbling cycles on seed quality, 10-liter lots of cones from each of the two Thunder Bay collections were cycled 16 times by method A. These seeds were subsequently dewinged and cleaned. Germination tests were then conducted on four 100-seed replicates per extraction cycle as described above, but at constant temperatures of 10, 21, and 32 °C (2), and with a longer germination period (45 days) for the 10 °C tests.

In addition, after empty seeds were removed by flotation in absolute ethyl alcohol, four more 100-seed replicates from each extraction cycle were weighed. These were then sown on the surface of a 2:1 peat/vermiculite growing medium, placed in a heated greenhouse (18 to 23 °C) lighted 16 hours a day, and watered daily. After they developed primary needles, the seedlings were fertilized every second day with 50 parts per million nitrogen (20-20-20 NPK). Seedling heights and dry weights were determined after 20 weeks.

Germination characteristics were examined in terms of germination capacity (the proportion of full seed that germinated), uniformity of germination (time in days from the beginning of germination until 90 percent of the viable seed had germinated), and germination speed (time in days from sowing until 50 percent of the viable seed had germinated) for each replicate. Following transformation (arcsine) of germination capacity values, data were compared by analysis of variance techniques. Differences among treatment means were established with Tukey's multiple comparison test. Results are reported as mean values per treatment.

Table 1—*Average yields of fully developed seeds per cone following 16 extraction cycles*



Collection	Extraction method	Sample size (cones)	Total seed extracted	Total seed remaining in cone	Viable seed extracted	Percent viability
Sault Ste. Marie	A	50	80.0	ND	37.0	46
Thunder Bay, 1979	A	40	79.8	5.4	48.4	61
Thunder Bay, 1980	A	40	69.4	11.8	34.0	49
Thunder Bay, 1979	B	40	84.5	1.9	47.8	57
Thunder Bay, 1980	B	40	80.2	1.8	44.1	55

ND = not determined.

Results and Discussion

Mean seed yields after 16 extraction cycles ranged from 69 to 85 fully developed seeds per cone and from 34 to 48 viable seeds per cone (table 1), with an average of 2 to 12 fully developed seeds still remaining in each cone. As expected, yields per cycle decreased in later extractions (fig. 1). However, it is noteworthy that the second, third, and often the fourth cycles yielded more seeds than the first. This suggests that specific treatment may be required to enhance cone scale flexing and seed release.

Seed yields per cycle appeared to be affected by both cone storage and extraction methods (fig. 1). Cones stored at room temperature in paper bags (the Sault Ste. Marie collection) had dried and opened to some extent prior to extraction. They yielded greater quantities of seed during the first two cycles with method A than did those stored at 0.5 °C (the Thunder Bay collections). A significantly larger portion of the total seed yield was obtained by the first two or three cycles with extraction method B than with method A.

The proportion of extracted seed that was viable tended to be somewhat larger (by 5 to 15 percent) for the first three cycles, but thereafter exhibited no distinct trend. Average viability (all collections and extractions combined) was 60 percent for cycles 1 to 3 but only 48 percent for cy-

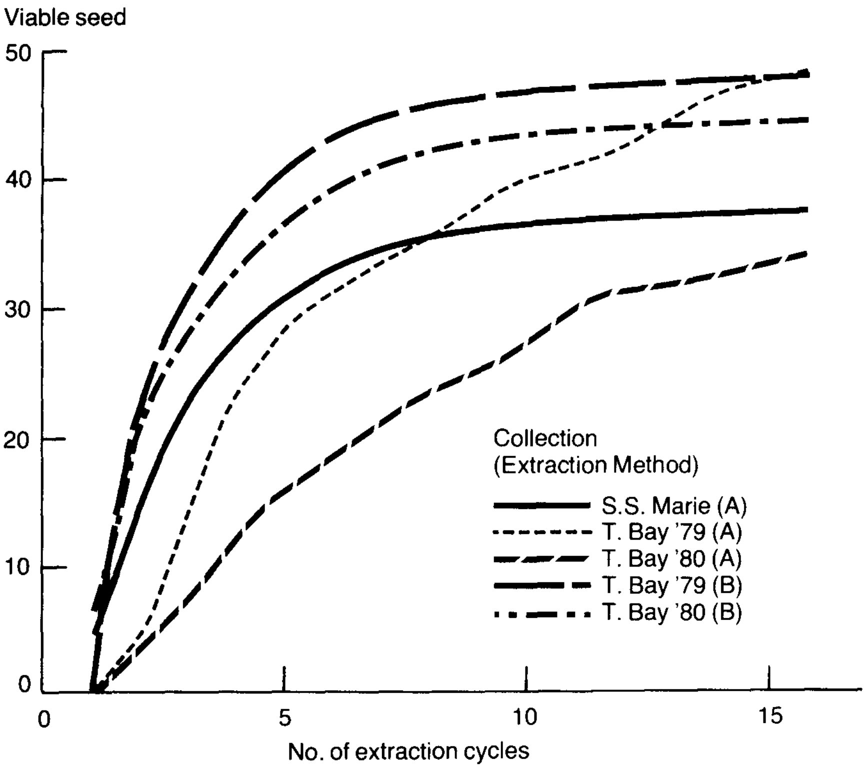


Figure 1—*Cumulative viable seed yields per cone by number of extraction cycles.*

cles 4 to 16. The drop in viability for later extractions reflected an increase in the proportion of empty seed, not a decrease in the viability of full seed. For almost all combinations of seed collection, extraction methods, and extraction cycle, over 90 percent of the full seed obtained was viable.

Although the number of viable seeds per cone can vary dramatically, these results suggest that healthy black spruce cones often contain considerably more viable seeds than are generally extracted. Comprehensive studies are needed to identify more efficient cone storage and extraction techniques to improve yields from large-scale facilities (3). When small lots are processed by methods similar to those employed here, substantial quantities of viable seed (>- 2 seeds/ cone) may be obtained through the sixth extraction cycle. Determinations of the number of viable seeds per cone based on two or three extraction cycles (8) can underestimate the true figure by as much as 50 percent.

To gain a better understanding of the effects of repeated extraction cycles on seed quality, we conducted germination tests at Fraser's (2) lower, optimum, and upper cardinal germination temperatures for black spruce. The germination capacity of the seeds was not significantly different for the first 6 to 7 extractions, regardless of germination temperature. Thereafter it decreased somewhat at 10 °C, but not at 21 or 32 °C. The speed and uniformity of germination tended to decline for later extractions, particularly at 10 °C (figs. 2 and 3). However, there was no significant difference in these two characteristics among seeds from the first 4 to 6 extractions at 10 °C, and from at least the first 5 to 6 extractions at 21 and 32 °C.

Direct relationships have often been reported between seed weight and germination or early growth characteristics. Skeates (9) found a direct correlation between black spruce seed weight and the size of first-year seedlings. In the present study the average weight of full seed decreased somewhat for later extractions, but significant reductions were not realized until the eleventh or twelfth cycle.

The greenhouse study was carried out to determine the effects of repeated soaking and tumbling on germination in a growing medium and on early

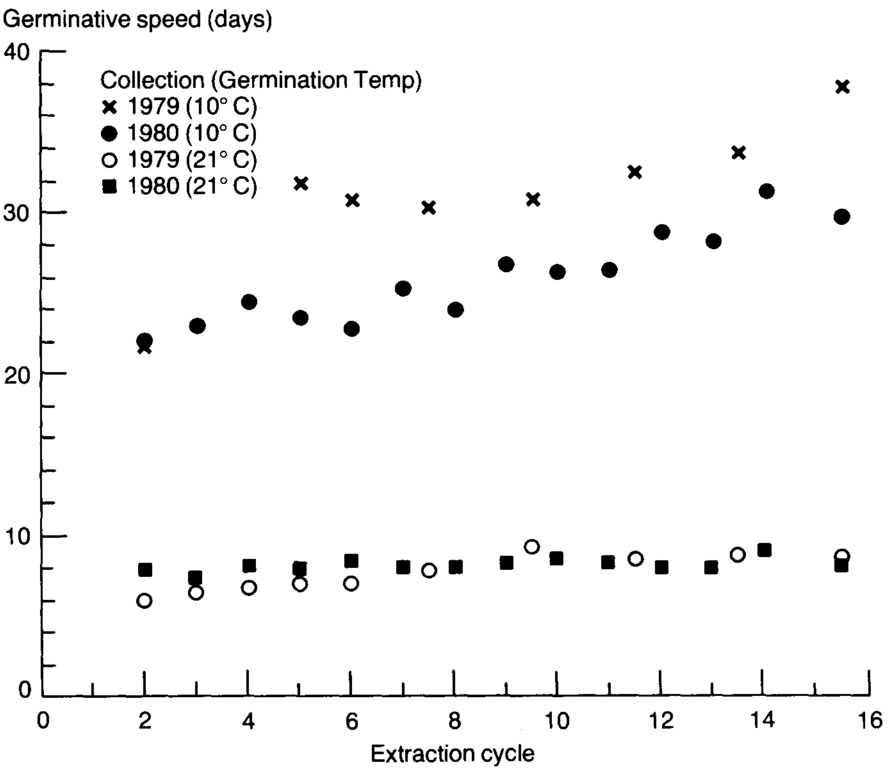


Figure 2—*Germinative speed at two temperatures for successive extractions from two collections. (Results at the 32 °C germination temperature were similar to those at 21 °C, and therefore are not presented.)*

growth. Seeds sown in the greenhouse exhibited germination characteristics similar to those exhibited by seeds incubated in cabinets at 21 °C; there were no significant differences in germination capacity among extractions, but the speed and uniformity of germination declined significantly by the eighth to twelfth cycle. Nevertheless, after 20 weeks, no significant differences were found between extraction cycles for survival, height, and dry weight of the resulting seedlings.

The gradual but consistent drop in the quality of seed from later extraction cycles may be of concern. While seed from later extraction cycles produces healthy and vigorous greenhouse seedlings, it may not perform as well in field conditions where germination temperatures are considerably lower (i.e., in outdoor nurseries or direct seeding programs), or following storage. The drop in seed quality following repeated extractions is likely to vary, depending on the extraction process and number of cycles employed. Hence, while reprocessing cones should be considered as an immediate step to improve seed yields, tests should be conducted to ensure that the additional seed procured is of sufficient quality to warrant this treatment.

Over the long term, refinements in cone storage and extraction techniques likely offer greater potential for increasing yields of high quality seed than does reprocessing with current technology.

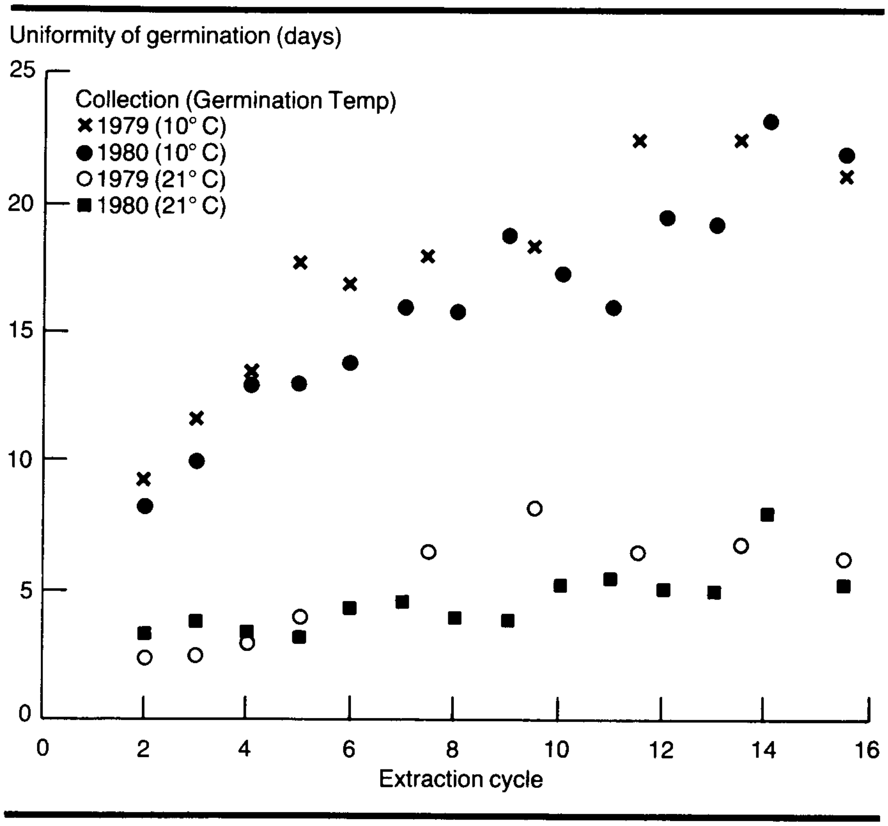


Figure 3—*Uniformity of germination at two temperatures for successive extractions from two collections. (Results at the 32 °C germination temperature were similar to those at 21 °C, and therefore are not presented.)*

Literature Cited

1. Bramlett, D.L.; Belcher, E.W., Jr.; DeBarr, G.L.; and others. Cone analysis of southern pines, a guidebook. Gen. Tech. Rep. SE-13. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeast Forest Experiment Station; and Atlanta, GA: Southeast Area, State and Private Forestry; 1977. 28 p.
2. Fraser, J.W. Cardinal temperatures for germination of six provenances of black spruce seed. Inf. Rep. PS-X-23. Chalk River, ON: Canadian Forestry Service, Department of Fisheries and Forests; 1970. 11 p.
3. Hellum, A.K. Lodgepole pine seed extraction. In: Huber, R.F. (comp.). High-quality collection and production of conifer seed. Inf. Rep. NOR-X-235. Edmonton, AB: Canadian Forestry Service, Department of the Environment; 1981. 11 p.
4. Janas, P.S.; Haddon, B.D. Canadian forest tree seed statistics: 1980-81 survey results. Inf. Rep. PI-X-41. Chalk River, ON: Canadian Forestry Service, Department of the Environment; 1984. 16 p.
5. Millar, J.B. The silvicultural characteristics of black spruce in the clay belt of northern Ontario. MS thesis; Toronto, ON: University of Toronto, Faculty of Forestry; 1936. 81 p.
6. Manley, A.L. Seed yield of immature black spruce (*Picea mariana* (Mill.) B.S.P.) plantations in southcentral New Brunswick. MS thesis; Fredericton, NB: University of New Brunswick, Faculty of Forestry; 1978. 31 p.
7. O'Reilly, C.; Parker, W.H.; Barker, J.E. Effect of pollination and strobili number on random mating in a clonal seed orchard of *Picea mariana.* Silvae Genetica 31:90-94; 1982.
8. Safford, L.O. Picea A. Dietr. spruce. In: Schopmeyer, C.S. (tech. coord.). Seeds of woody plants in the United States. Agr. Handb. 450. Washington, DC: U.S. Department of Agriculture; 1974: 587-597.
9. Skeates, D.A. Size and weight of tubed seedlings related to size, density, and weight of seed in jack pine, black spruce, and white spruce. MS thesis; Toronto, ON: University of Toronto, Faculty of Forestry; 1972. 88 p.
10. Smith, E.P.; Woodcock, W. Mechanical black spruce cone harvesting. Kirkwood Lake, ON: Heathwood Engineering Associates; 1981. 75 p.

Effect of Fall Sowing and Solar Heating of Soil on Two Conifer Seedling Diseases

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Solar heating did not reduce Macrophomina phaseolina *at any soil depth and eliminated* Fusarium oxysporum *f. sp.* pini *in the top 10 centimeters only. Fall sowing of* Abies concolor *and* Pseudotsuga menziesii *did not reduce disease, but did result in taller seedlings than did spring sowing.* Tree Planters' Notes 37(4):17-20; 1986.

Conifer seedlings are susceptible to a number of common soilborne fungi, including *Rhizoctonia solani* Kuehn, *Pythium* spp., *Phytophthora* spp., *Fusarium oxysporum* (Schlecht.), and *Macrophomina phaseolina* (Tassi) G. Goid. (10). These pathogens are controlled primarily by fumigation with a methyl bromide-chloropicrin mixture applied in the late summer or fall when the soils are warm.

A cover crop, usually vetch (*Vicia sativa* L.), is sown in the fall to control winter soil erosion.

In spring, as early as weather permits, the cover crop is turned under, and the soil is prepared for sowing. Sowing is usually done in April or May. Recent research with *Pinus lambertiana* Dougl. has shown that early sowing (before March 15) results in larger seedlings and reduced losses from disease (3).

Solar heating (solarization) of soil for control of soilborne pathogens is an accepted disease control practice in agricultural regions with high summer temperatures (4) and has been effective in reducing damping-off in a forest tree nursery (2). The purpose of this study was to determine the effectiveness of solar heating for controlling soilborne pathogens of conifer seedlings in a California forest tree nursery and to evaluate the effect of fall sowing on seedling growth and survival. A preliminary report has been published (6).

Material and Methods

Two nursery experiments were conducted at the Institute of Forest Genetics (Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture), Placerville, CA. The nursery is situated on a broad ridge below the snow line in the American River watershed of the western Sierra Nevada (38°45' N. 120°44' W). Elevation is 838 meters, and the soil is Aiken clay loam (11).

Experiment 1. In 1981, inocula of *F. oxysporum* (originally isolated from *P. lambertiana* and grown on autoclaved, chopped alfalfa hay) and inoculum of *M. phaseolina* (recovered from soil) were rototilled into the top 15 centimeters of soil. The soil was brought to field capacity, and then covered with 0.1-millimeter-thick clear polyethylene from July 1 to September 9.

The sampling design consisted of four solarized and four nonsolarized areas each measuring 1.5 by 7.5 meters arranged in randomized blocks. Nylon mesh bags containing 25 grams of soil infested with *F. oxysporum* f. sp. *pini* and *M. phaseolina* were buried along with thermocouples at depths of 0, 2.5, 10, 20, 30, and 40 centimeters.

The nylon bags were retrieved at the end of the solarization period, and the propagule levels were determined according to the methods of Komada (S) and McCain and Smith (7).

For fall sowing, seeds of rape (*Brassica napus* L.), annual ryegrass (*Lolium multiflorum* Lam.), and common vetch (*Vicia sativa* L.) were sown on November 3 in rows located between 1.5-m rows of seeds of P. *lambertiana* spaced 7.5 cm apart.

Eighteen rows of *P. lambertiana* were sown for a total of 360 seeds per cover crop subplot in the solarized and nonsolarized plots. Nonplanted areas were reserved for spring sowing. Cover crops were killed by spraying with glyphosate on March 24, 1982, prior to emergence of the conifer seedlings. *P. lambertiana* seeds for the spring sowing on April 22, 1982, had been soaked for 36 hours in aerated water at 25 °C, drained, and placed in polyethylene bags held at 1 °C for 90 days.

Experiment 2. A similar solarization trial was conducted in 1982. The solarized and nonsolarized subplots were smaller than before (1.5 by 3.7 meters), and thermocouples were buried with mesh bags of infested soil at depths of 10, 20, and 30 centimeters. The 0.05-millimeter-thick polyethylene solarization covers were placed on June 17 and removed on August 22, 1982. Vetch seeds were distributed throughout the fall planting subplots and 3 species of conifers-*Pinus lambertiana, Pseudotsuga menziesii* (Mirb.) Franco, and *Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.-were sown on October 4, 1982. The vetch was removed by hand on April 4, 1982, because some conifer seedlings had emerged and application of herbicide might have damaged them. Spring sowing was done on May 4, 1982.

A mechanical pyranograph (Weathermeasure 8401) recorded solar radiation in both the 1981 and 1982 trials.

Isolations from dead or dying conifer seedlings were grown on water agar plus 1- to 2-millimeter bits of propylene oxide-sterilized pea straw.

Height measurements were made in October, after the seedlings ceased apical growth.

Results

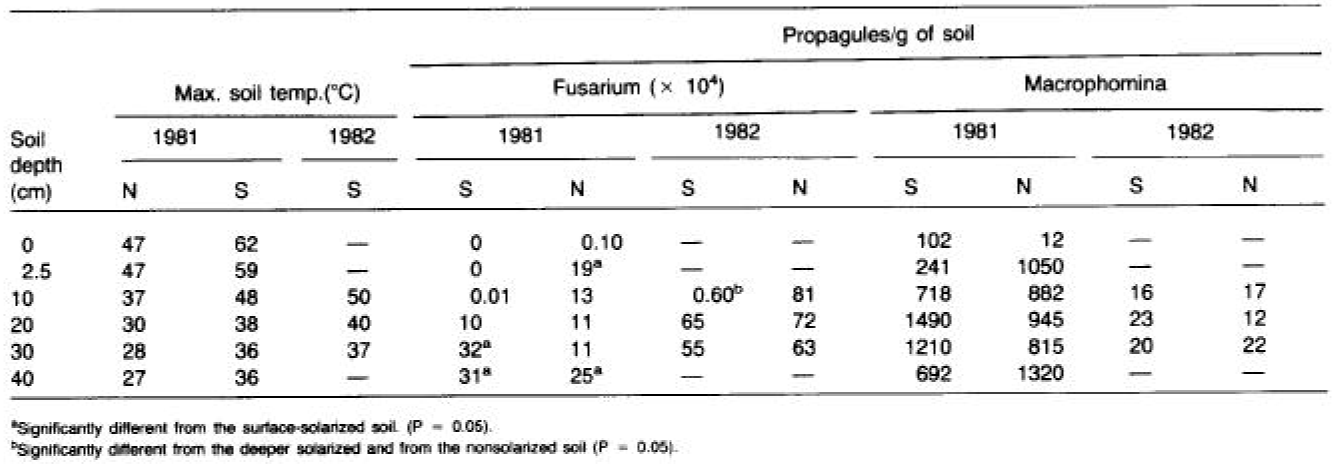
In 1981 the weather during the 55-day solarization treatment was clear except for partly cloudy days on July 22 and August 18. The maximum solar radiation on July 15 was 1.05 calories per square centimeter per minute and on September 9 it was 0.855. The relative humidity averaged 26 percent, and the maximum and minimum air temperatures were 34.4 °C and 19.4 °C. Soil temperatures beneath the polyethylene tarps were maximum between July 28 and August 14.

In 1981 the rototilled soil contained an average of 8.4 propagules per gram of *M. phaseolina* before solarization. After solarization, the average was 5.1 propagules per gram of *M. phaseolina* in the solarized plots and 30 propagules per gram in the nonsolarized plots. After rototilling and prior to solarization the soil contained 1.9×10^3 propagules of *F. oxysporum* f. sp. *pini.* After solarization the level of *F. oxysporum* had dropped to 8.5 propagules per gram in the solarized soil and 1.2×10^3 in the nonsolarized plots.

There were 31 cloudy days during the 66-day solarization period in 1982 with rain on several of those days. The maximum solar radiation, 1.07 calories per square centimeter per minute, was recorded on July 4 and the lowest value, 0.885, was recorded on August 22. During the solarization period the average relative humidity was 38 percent, the maximum air temperature of 36.7 °C occurred on July 13 and the minimum air temperature of 8.3 °C occurred on July 4. Solarization was interrupted for 10 days beginning on July 29 because of wind damage to the polyethylene sheeting. The 0.05-millimeter-thick polyethylene was not strong enough for the wind conditions that occurred during the summer of 1982.

In 1982 the rototilled soil contained an average of 15 propagules per gram of *M. phaseolina* and 1.1×10^3 propagules per gram of *F. oxysporum*. After solarization, the average was 8.2 propagules per gram of *M. phaseolina* in the solarized plots and 14 propagules per gram in the nonsolarized plots, whereas 5.4 propagules per gram of *F. oxysporum* were detected in samples taken from

Table 1—*Survival of* Fusarium oxysporum *and* Macrophomina phaseolina *in solarized (S) and nonsolarized (N) soil*



Soil depth (cm)	Max. soil temp.(°C)			Propagules/g of soil							
				Fusarium (× 10^4)				Macrophomina			
	1981		1982	1981		1982		1981		1982	
	N	S	S	S	N	S	N	S	N	S	N
0	47	62	—	0	0.10	—	—	102	12	—	—
2.5	47	59	—	0	19[a]	—	—	241	1050	—	—
10	37	48	50	0.01	13	0.60[b]	81	718	882	16	17
20	30	38	40	10	11	65	72	1490	945	23	12
30	28	36	37	32[a]	11	55	63	1210	815	20	22
40	27	36	—	31[a]	25[a]	—	—	692	1320	—	—

[a] Significantly different from the surface-solarized soil. (P = 0.05).
[b] Significantly different from the deeper solarized and from the nonsolarized soil (P = 0.05).

the top 10 centimeters of solarized soil and an average of 4.9 x 10^2 from the nonsolarized plots.

The magnitude and duration of the temperatures achieved in both 1981 and 1982 were sufficient to achieve control of *F. oxysporum* in the surface soil but not at greater depths. *M. phaseolina* was not controlled at any depth although there may have been some reduction in propagule survival in the bare surface soil (table 1).

Rodents ate most of the *P. lambertiana* seeds in the 1981 fall and spring sowings, and no significant survival or growth measurements were possible. The three cover crops made satisfactory growth in the fall and would have provided erosion control on sloping land. Vetch was chosen for the 1982 trial because it is commonly used for erosion control and appeared to cause minimal disruption of the conifer seeds.

Rodents again ate the fall-planted *P. lambertiana* seeds in 1982 and mortality from disease could not be accurately assessed. There was no significant difference in survival between the fall and spring sowings of *A. concolor* and *P. menziesii*. There were differences in the populations of pathogens involved in mortality. Diseased seedlings from solarized plots yielded *M. phaseolina*, whereas seedlings from nonsolarized plots primarily yielded *F. oxysporum*.

No benefit in seedling survival from the solarization treatment was detected in either 1981 or 1982.

Seedlings of *A. concolor* and *P. menziesii* that developed from fall-sown seeds were larger than those from the spring sowing. Seedlings from fall-sown *P. lambertiana* were also larger but this difference was not statistically significant in this trial (table 2).

Discussion

Fall and winter sowings most closely simulate natural environmental conditions for seed germination, seedling emergence, and early growth (3). The major advantage of fall sowing is the ease of soil preparation and planting during favorable weather. Fewer soil preparation operations are necessary with fall planting, and it is unnecessary to cold treat the seed because this occurs in the field.

However, possible rodent damage is a major disadvantage of fall sowing. In this study the nursery beds were adjacent to

Table 2—*Survival and growth of conifer seedlings in fall and spring sowings in solarized (S) and nonsolarized (N) soil*

	Survival (%)		Height (mm)	
	S	N	S	N
Abies conconor				
Fall	62.5	52.1	62*	84*
Spring	43.6	51.1	42	43
Pinus lambertiana				
Fall[1]	3.4	4.1	165	117
Spring	87.5	88.0	132	117
Pseudotsuga menziesii				
Fall	56.2	70.4	115*	145*
Spring	66.1	72.0	88	113

*Significantly different ($P = 0.05$).
[1] Poor survival because of rodents.

uncultivated areas that harbored the rodents. This situation should be considerably less of a problem in large nurseries, and poisons could be applied to the seeds to eliminate the rodents.

The failure of fall sowing in these trials to reduce mortality due to disease was probably related to the high inoculum levels of *F. oxysporum* and *M. phaseolina* in the soil. Fall sowing into fumigated soil should result in the production of superior healthy seedlings.

It is not surprising that *M. phaseolina* was not controlled by solar heating of soil, for sclerotia of the fungus are resistant to prolonged high temperatures *(1). M. phaseolina was* not eliminated by soil solarization in trials conducted in Arizona (9).

It may be possible to control conifer seedling diseases through solar heating of soil where *M. phaseolina* is absent or in very low numbers. The monitoring of nursery soil for sclerotia of the fungus would be a simple matter because improved assay methods are available (8).

Literature Cited

1. Bega, R.V.; Smith, R.S. Time-temperature relationships in thermal inactivation of sclerotia of *Macrophomina phaseoli.* Phytopathology 52:632-635; 1962.
2. Hildebrand, D.M. Soil solar heating for control of damping-off fungi and weeds at the Colorado State Forest Service Nursery. Tree Planters' Notes. 36(1):28-34; 1985.
3. Jenkinson, J.L.; Bega, R.V.; McCain, A.H. Winter sowings increase size and survival of nursery seedlings of sugar pine in the Sierra Nevada of California. Proceedings, Reunion Tecnica Principios de Introduccion de Especies; 1982 October 4-8; Lourizan, Spain. 1982.
4. Katan, J. Solar heating (solarization) of soil for control of soilborne pests. Annual Review of Phytopathology 19:211-236; 1981.
5. Komada, H. Development of a selective medium for quantitative isolation of *Fusarium oxysporum* from natural soil. Review of Plant Protection Research 8:114-125; 1975.
6. McCain, A.H.; Bega, R.V.; Jenkinson, J.L. Solar heating fails to control *Macrophomina phaseolina.* Phytopathology 72:445 (Abstr.); 1982.
7. McCain, A.H.; Smith, R.S., Jr. The quantitative assay of *Macrophomina phaseoli* from soil. Phytopathology 62:1098; 1972.
8. Mihail, J.D.; Alcorn, S.M. Quantitative recovery of *Macrophomina phaseolina* sclerotia from soil. Plant Disease 66:662-663; 1982.
9. Mihail, J.D.; Alcorn, S.M. Effects of soil solarization on *Macrophomina phaseolina* and *Sclerotium rolfsii* Plant Disease 68:156-159; 1984.
10. Peterson, G.W.; Smith, R.S., Jr. Forest nursery diseases in the United States. Agric. Handbk. 470. Washington, DC: U.S. Department of Agriculture, Forest Service; 1975. 125 p.
11. Rogers, J.H. Soil survey of El Dorado area, California. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service and Forest Service in cooperation with University of California Agricultural Experiment Station and Nevada Experiment Station; 1974. 844 p.

Propagation of Red Alder (*Alnus rubra* Bong.) by Mound Layering

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*Mound layering using 2-year-old nursery-grown seedlings of red alder (*Alnus rubra *Bong.) produced about seven rooted sprouts per stump. Most survived separation from the parent plants, and all had strong, upright growth habits.* Tree Planters' Notes 37(4):21-23; 1986.

Red alder (*Alnus rubra* Bong.) is the most common hardwood in the Pacific Northwest. It is anticipated that the importance of this species for wood products or as a nitrogen fixer may reach a point where genetic improvement will be desirable. Because considerable variation exists in red alder (3), the genetic improvement potential seems high. Such genetic improvement could achieve immediate gains if the best trees could be cloned to produce numerous individuals for field planting (2,5).

Little information has been reported on the vegetative propagation of red alder. However, excellent rooting results with greenwood cuttings taken from 1- to 3-year-old seedlings have been achieved (7). Another method of vegetative propagation that we believe may show promise is mound layering. In mound layering, the stems of young plants are cut back to the ground and soil is heaped around the subsequent sprouts (6). It is commonly used to produce apple and quince root stocks (1).

Several sources of information led us to think that mound layering would work. For example, red alder planted in Hawaii, where the humidity is very high, showed a tendency to produce adventitious roots (4). In addition, from one of our own studies we found that the buried branches on some 2-year-old alder that were planted too deep had produced roots. We also knew from our frequent slashing of small alder reproduction out of research plots that each cut stem sprouted back vigorously each year with multiple stems.

We had good evidence, therefore, to believe that red alder could be vegetatively reproduced by mound layering. This technique can be carried out on a production basis in a nursery, without the use of greenhouses or special rooting beds. It has the potential to produce large plants in one growing season.

Methods

Red alder seed was sown in small outside nursery beds. After 2 years the plants had reached 2 meters in height and were 40 to 60 centimeters apart. The following January seven of these plants were cut back to 7 to 10 centimeters above ground. Many sprouts originated from each of the stumps and on June 1 when the sprouts were 20 to 25 centimeters tall the base of all the sprouts and the stumps were covered with 7 to 10 centimeters or more of nursery soil. The tips of the sprouts were never covered and none were pruned out to avoid crowding. Irrigation was provided during the summer on a regular basis. In March of the following year these 1-year-old sprouts were counted, measured for height, and examined for rooting.

Results

There were 71 exposed sprouts growing from the seven stumps at the start of the study. Of the 47 sprouts that survived the summer, all developed roots. The number of sprouts per stump ranged from 3 to 9, with an average of 6.7. Sprout heights ranged from 0.39 meters to 2.63 meters, with an average of 1.11 meters. The more sprouts in a clump, the greater the range in height.

The number of roots on each sprout varied considerably (figs. 1 and 2). Large sprouts lower on the same stump had more and larger roots, whereas the dominant sprout, which originated near the top of the stump, had the fewest roots. These uppermost sprouts were covered with less soil, so that they may have been too dry for good rooting. The sprouts were very limber at the time of mounding and some were forced down by the weight

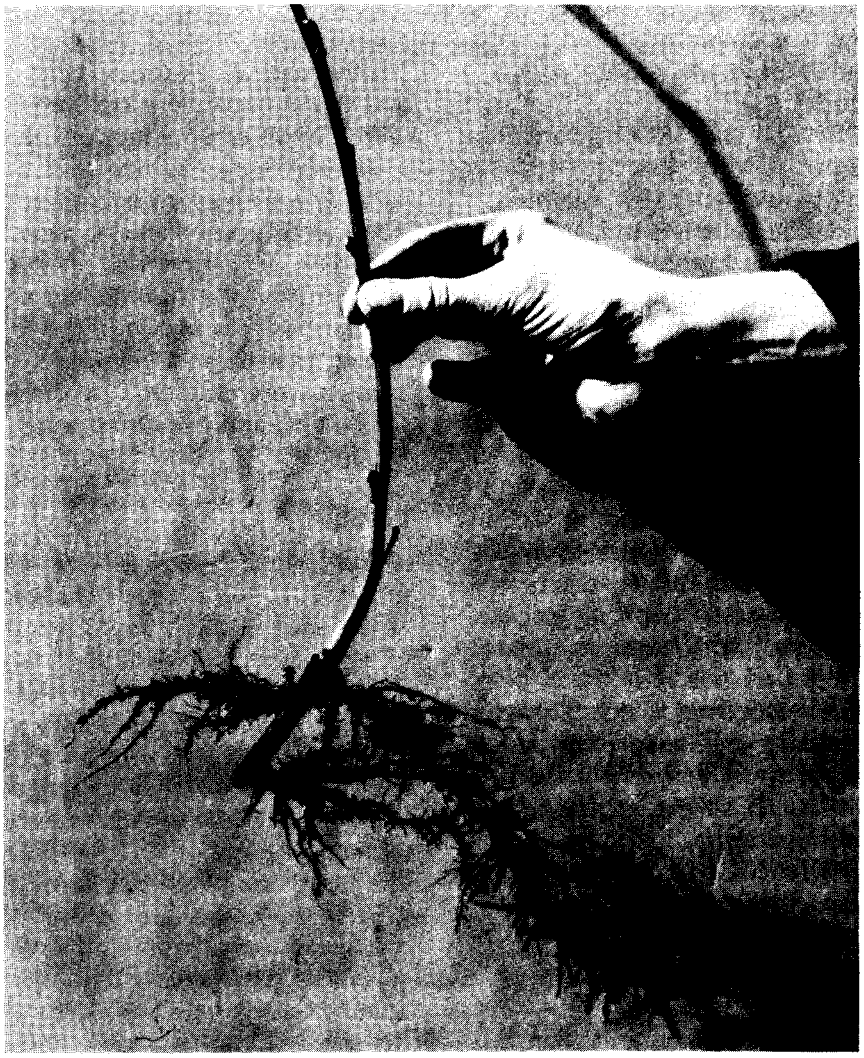

Figure 1—*A small red alder sprout with adequate rooting, held in its natural position.*

of the soil. These sprouts were covered over a greater length than the others, in one case a full 12 inches, and rooted well along the entire buried length.

Each clump of sprouts was dug up and examined. Most of the sprouts were well rooted and had well-developed mycorrhizae. Red alder is a nitrogen-fixing species and the roots on the new sprouts were also well nodulated. The rooted sprouts were easily cut from the parent stump and transplanted. If the stumps are left in place for annual production it may be more difficult to separate the rooted plants because of the heaped soil. However, heaping the soil on the sprouts so that they lay out and away from the parent stump may promote easier separation.

The transplanted rooted sprouts were grown for 1 year in a nursery bed and were regularly irrigated. With the exception of a few poorly rooted sprouts, all survived the growing season. Most were vigorous, and all were strongly orthotropic. Though not tested further, these rooted sprouts appeared to have excellent potential for continued growth and development.

Conclusions

Most of the sprouts were well rooted and vigorous and showed an upright growth habit. We therefore concluded that mound layering is an excellent method of reproducing selected clones of red alder. Established stumps spaced 2 feet apart should produce 5 to 8 sprouts per year at least 1 meter tall.

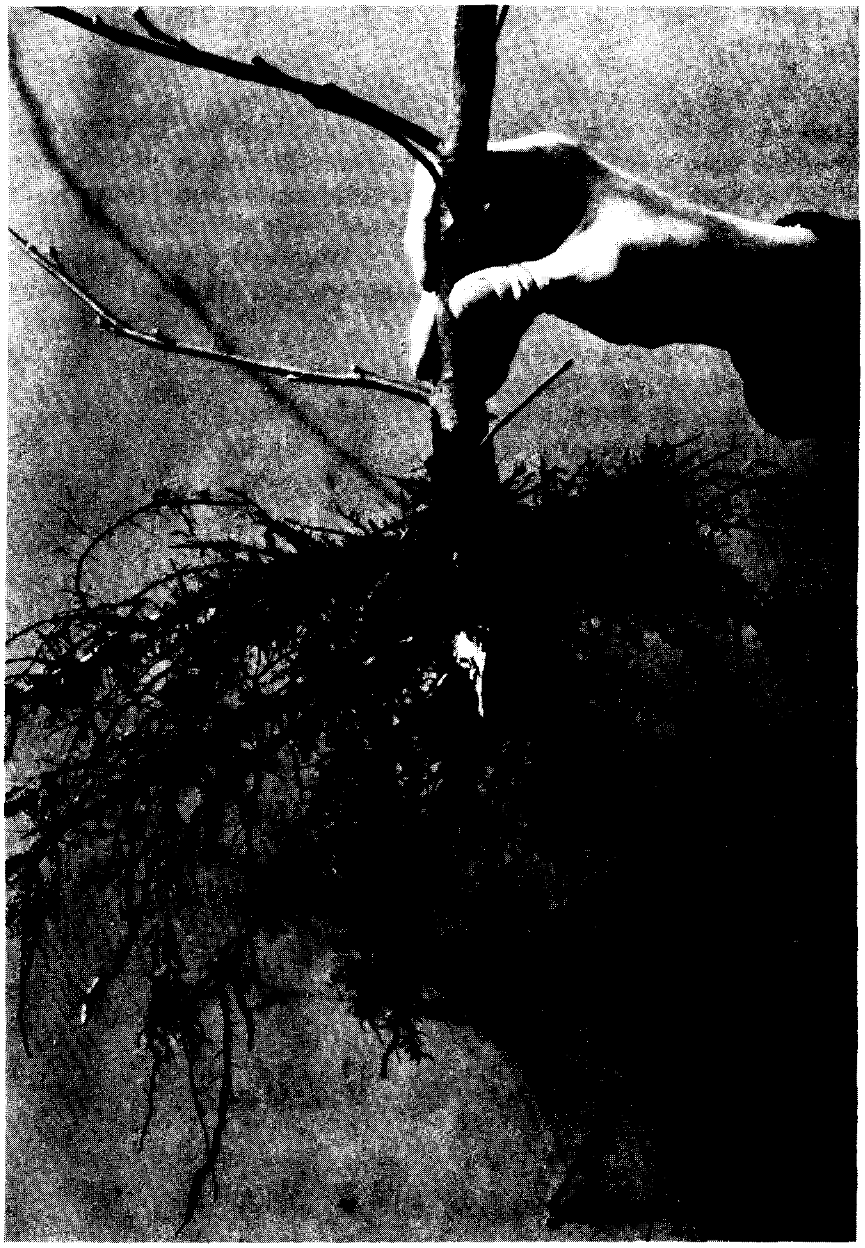

Figure 2—*One of the largest and best rooted red alder sprouts.*

Literature Cited

1. Adriance, G.W.; Brison, F.R. Propagation of horticultural plants. New York: McGraw-Hill Book Co.; 1955.
2. Brix, H.; Van den Driessche, R. Use of rooted cuttings in reforestation. Can. For. Serv. Joint Rep. 6. Vancouver, BC: British Columbia Forest Service; 1977.
3. DeBell, D.S.; Wilson, B.C. Natural variation in red alder. In: Briggs, D.G.; DeBell, D.S.; Atkinson, W.A. (comp.). Utilization and management of alder. Gen. Tech. Rep. PNW-70. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1978.
4. Lanner, R.M. Adventitious rooting: a response to Hawaii's environment. Res. Note PNW-54. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1964. 3 p.
5. Libby, W.J. Rooted cuttings in production forests. In: Proceedings, Fourteenth Southern Forest Tree Improvement Conference, Gainesville, FL. Publ. 36. Southern Forest Tree Improvement Committee; 1977. [Available from USDA Forest Service, National Tree Seed Laboratory, Dry Branch, GA].
6. Mahlstede, J.P.; Haber, E.S. Plant propagation. New York: John Wiley & Sons; 1957. 413 p.
7. Monaco, P.A.; Ching, T.M. Ching; K.K. Rooting of *Alnus rubra* cuttings. Tree Planters' Notes 31:22-24; 1980.

Comparison of Survival Enhancement Techniques for Outplanting on a Harsh Site in the Western Oregon Cascades[1]

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Bareroot seedlings of Douglas-fir (Pseudotsuga menziesii *(Mirb.) Franco) survived and grew better than container-grown stock planted on a droughty site in the western Cascade Mountains. Shading improved survival and growth, but field application of a solution of* Pisolithus tinctorius *basidiospores to the roots did not.* Tree Planters' Notes 37(4) :24-28; 1986.

Droughty sites on the west slope of the Oregon Cascade Range can be difficult to reforest after clearcutting, and intensified reforestation efforts are often needed. The use of container-grown seedlings, shading, or mycorrhizal inoculations may help regenerate these sites.

The performance of container-grown and bareroot seedling stock of Douglas-fir *Pseudotsuga menziesii* (Mirb.) Franco has been compared in field tests in Oregon (5,6,9,21). These studies suggest that container-grown stock survives better than bareroot stock on south-facing slopes or sites with rocky or shallow soil. Bareroot stock, which is generally larger, competes better than container stock with brush on wet sites or slopes with northern aspects.

Other studies have shown that shade can increase survival on droughty sites with southern exposures by reducing water stress and surface soil temperatures that may damage the seedling's cambium near the root collar (1,7,8,11,17,22).

The ectomycorrhizal fungus *Pisolithus tinctorius* (Pers.) Coker & Couch has demonstrated a tolerance to xeric, high-temperature sites with low fertility (12,13,16,23). Research to date has primarily involved inoculation of nursery seedlings (3,10,14,15,25). Applying basidiospores of mycorrhizal fungi to seedling roots in the field immediately before outplanting has logistic advantages, including ease of application and low costs.

The purpose of this experiment was to examine reforestation improvement methods for harsh sites by comparing survival and height growth of Douglas-fir seedlings after the first and third growing seasons. The following methods were compared: bareroot versus container-grown stock; shaded versus nonshaded seedlings; application of *Pisolithus tinctorius* basidiospores to seedling roots versus no application.

Methods and Materials

The experiment was installed in a clearcut on the west slope of the Cascade Mountains, 50 kilometers east of Sweet Home, Oregon. The site has a south-southwest aspect and an elevation of 1000 meters. It was logged in 1974 and broadcast-burned in 1976. Existing brush consisted of scattered, short (1.5-meter) clumps of rhododendron, salal, and vine maple. Adjacent forest communities are characterized by the *Tsuga heterophylla / Castanopsis chrysophylla* association (4). An intense broadcast burn; deer browsing; south-southwest exposure; and the shallow, skeletal soils had contributed to past reforestation failures.

We used a split block experimental design with six blocks. Each block of 400 seedlings had 100 trees in each of four treatments: (1) control, (2) shade, (3) spore application, and (4) shade and spore application. Within each treatment, 50 bareroot and 50 container-grown seedlings were installed in randomly arranged rows of 10 seedlings each. The data were analyzed

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[1] This study was conducted in cooperation with the U.S. Department of Agriculture, Forest Service, Willamette National Forest, Sweet Home Ranger District, and the Pacific Northwest Forest and Range Experiment Station, Forest Sciences Laboratory, Corvallis, OR.

using multivariate analysis of variance (18, 20). Tukey's honestly significant difference test for multiple comparisons (19, 24) was used to compare treatment means.

Seed used for both the bareroot and container-grown seedlings was collected from the appropriate seed zone. Container trees were 1-0 stock grown in Ray Leach pine cells (65 cubic centimeters) at Beaver Creek Nursery near Philomath, Oregon, and were mostly nonmycorrhizal when spores were applied. The bareroot seedlings were 2-0 stock grown at Wind River Nursery near Carson, Washington, and had some mycorrhizae.

The basidiospores were provided by Dr. James Trappe of the Forestry Sciences Laboratory in Corvallis, Oregon. Sporocarps had been collected the previous fall, then dried and refrigerated. Spores were extracted March 1980 and stratified by soaking in cold water for a week. Bareroot seedlings were dipped in a spore solution slurry at the planting site and container seedlings were watered with the spore solution the day before. Spore concentration and water usage were such that the roots of each seedling, of both stock types, received about 1 milligram of spores.

Seedlings were hand planted in early May 1980 at a 3-foot spacing. Shading was provided with slitted, waxed cardboard rectangles (25 by 50 centimeters) slipped on and stapled to wooden lath that was staked on the southwest side of appropriate trees. Existing brush was cut by hand to eliminate natural shade. Deer browse was reduced with big-game repellent. Survival and leader growth were measured in October of 1980 and 1982.

Results and Discussion

There were no significant interactions between treatments and stock types in either the first or third year survival or leader growth analyses, so interpretation of the results was straightforward.

Bareroot stock survived and grew in height significantly (P = 0.01) better than container-grown stock the first year. After 3 years, survival still differed significantly (P = 0.05), but height growth did not (fig. 1).

Shaded seedlings survived significantly better after both the first (P = 0.01) and third (P = 0.05) growing seasons than did unshaded seedlings, regardless of spore application. Spore application did not significantly affect survival. Shaded-only seedlings had grown significantly (P = 0.05) more than spore-application-only seedlings after the first year. After 3 years no significant growth differences remained among the treatments (fig. 2).

Stereo-microscope (3 to 5 times magnification) examination of first- and third-year roots of selected seedlings showed no development of *Pisolithus tinctorius* mycorrhizae.

The poor performance of container-grown stock in our study conflicts with recent reports of better survival of container-grown seedlings on south-facing, droughty sites (6,9). Our container stock may have sustained root damage during a hard freeze the previous winter, as suggested by some early summer mortality. The smaller stems of the container-grown seedlings may also have been more easily damaged by rough handling during planting.

In spite of their small size, surviving container seedlings had as much leader growth as bareroot seedlings by the third year. Also, survival of bareroot stock declined by 26 percent between the first and third year, whereas container-grown seedling survival declined only 4 percent during the same period. Clearly, many factors influence the relative long-term benefits of using these stock types.

Our shading results concur with the literature, but survival differences were small (less than 20 percent). The first growing season was moist and cool, which possibly reduced the benefits of shade during a more typical growing season. As of 1980, the cost for materials and installation of artificial shade approached $180.00 per acre. Closer initial seedling spacing would have been more cost-effective on this site, given the first growing season's weather. Shade is justified when other treatments cannot reasonably ensure acceptable stocking levels.

Although planting nursery inoculated mycorrhizal seedlings may enhance survival, the application of *Pisolithus tinctorius* spores to a seedling's roots immediately preceding outplanting appears to be ineffective. Alvarez and Trappe (2) hypothesized that dusting roots with spores before outplanting was ineffective or harmful because a dense coating of hydrophobic spores would inhibit water uptake by the seedlings. This was not the case in our study, because spores were applied in a liquid suspension; however, the lack of *Pisolithus tinctorius* mycorrhizae formation argues against the effectiveness of this technique.

Project costs for field application of basidiospores to seedling

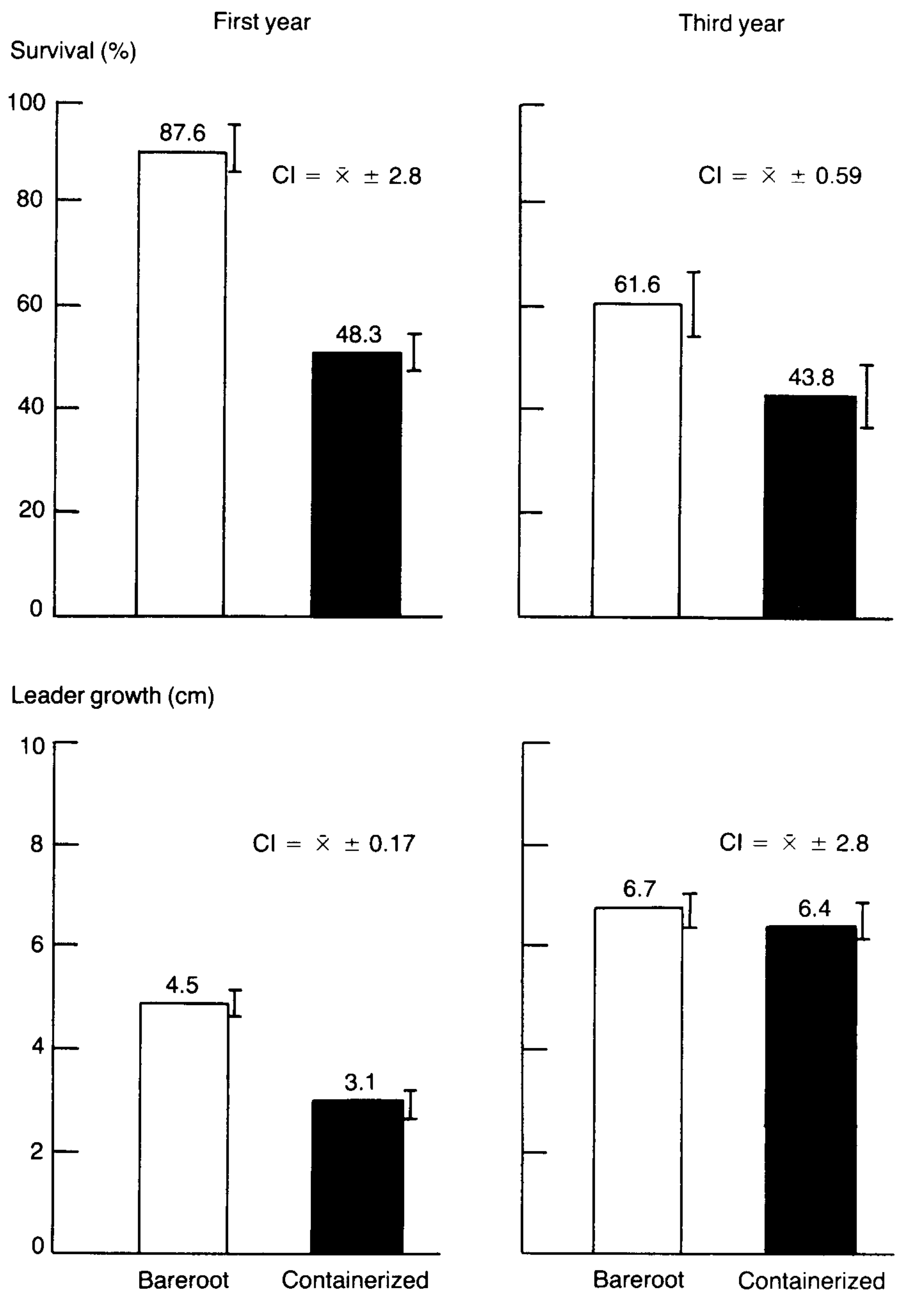

Figure 1—*Survival and growth of outplanted Douglas-fir seedlings by stock type.*

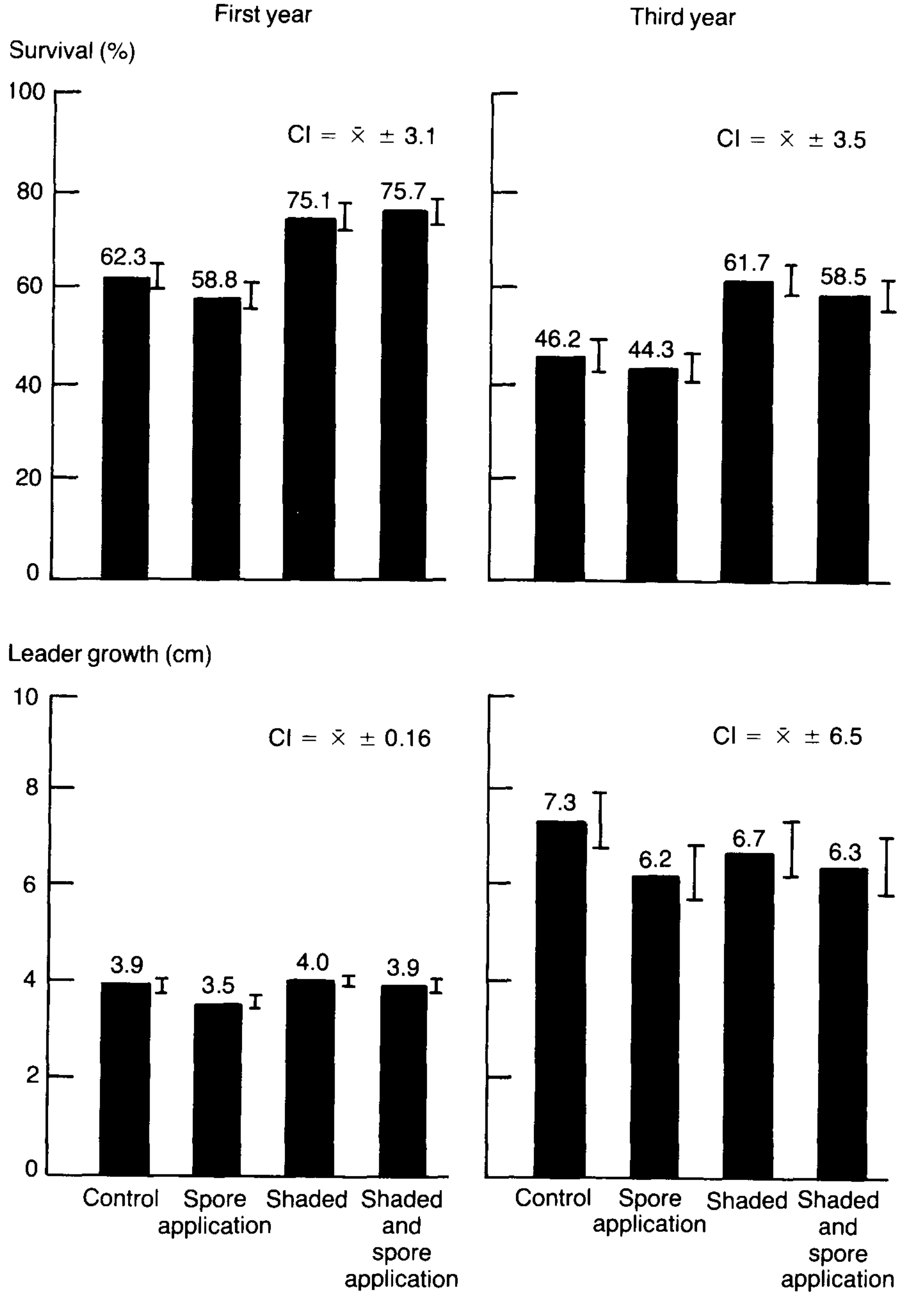

Figure 2—*Survival and growth of outplanted Douglas-fir seedlings by planting treatment.*

roots are negligible. If survival or growth could be enhanced by 1 or 2 percent, this technique could prove to be cost-effective. Further experimentation with different fungi, spore concentrations, or spore germination treatments would be worthwhile.

Literature Cited

1. Adams, R.S.; Ritchey, J.R.; Todd, W.G. Artificial shade improves survival of planted Douglas-fir and white fir seedlings. State For. Note 28. Sacramento, CA: California Division of Forestry; 1966. 11 p.
2. Alvarez, I.F.; Trappe, J.M. Dusting roots of *Abies concolor* and other conifers with *Pisolithus tinctorius* spores at outplanting time proves in effective. Canadian Journal of Forestry Research 13(5):1021-1023; 1983.
3. Bowen, G.C.; Theodorou, C. Growth of ectomycorrhizal fungi around seeds and roots. In: Marks, G.C., Kozlowski, T.T. (eds.). Ectomycorrhizae: their ecology and physiology. New York: Academic Press; 1973: 107-150.
4. Franklin, J.F.; Dyrness C.T.; Natural vegetation of Oregon and Washington. Gen. Tech. Rep. PNW--8 Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1973.
5. Gutzwiler, J.R.; Winjum, J.K. Performance of containerized coniferous seedlings in recent forest re generation trials in Oregon and Washington. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E. (eds.). Proceedings, North American containerized forest tree seed ling symposium, Great Plains Agric. Counc. Publ. 68 pp. 1974.

6. Hahn, P.F.; Smith, A.J. Douglas-fir planting stock performance comparison after the third growing season. Tree Planters' Notes 34(1):33-38; 1983.
7. Hobbs, S.D. Performance of artificially shaded container-grown Douglas-fir seedlings on skeletal soils. Res. Note 71. Corvallis, OR: Oregon State University, Forest Research Laboratory; 1982.
8. Hobbs, S.D.; Byars, R.H.; Henneman, D.C.; Frost, C.R. First year performance of 1-0 containerized Douglas-fir seedlings on droughty sites in Southwest Oregon. Res. Pap. 42. Corvallis, OR: Oregon State University, Forest Research Laboratory; 1980. 16 p.
9. Hobbs, S.D.; Lavender, D.P.; Wearstler, Jr., K.A. Performance of container-grown Douglas-fir on droughty sites in Southwest Oregon. In: Proceedings, Canadian Containerized Tree Seedling Symposium, Toronto, September 14-16, 1981.
10. Landis, T.D.; Gillman, L.S. Mycorrhizal inoculation of container-grown Ponderosa pine seedling. Tech. Rep. R2-3. Lakewood, CO: U.S. Department of Agriculture, Forest Service, Region 2; 1976.
11. Lewis, R.; Ritter II, C.J.; Wert, S. Use of artificial shade to increase survival of Douglas-fir in the Roseburg area. Tech. Note 321. Denver, CO: U.S. Department of the Interior, Bureau of Land Management; 1978.
12. Marx, D.H. Tree host range and world distribution of the ectomycorrhizal fungus *Pisolithus tinctorius*. Canadian Journal of Microbiology 23(3):217-223; 1977.
13. Marx, D.H.; Bryan, W.C. Influence of ectomycorrhizae on survival and growth of aseptic seedlings of loblolly pine at high temperatures. Forest Science 17:37-41; 1971.
14. Marx, D.H.; Bryan, W.C. Growth and ectomycorrhizal development of loblolly pine seedlings in fumigated soil infested with the fungal symbiont *Pisolithus tinctorius*. Forest Science 22(3):245-254; 1975.
15. Marx, D.H.; Bryan, W.C.; Cordell, C.E. Growth and ectomycorrhizal development of pine seedlings in nursery soils infested with the fungal symbiont *Pisolithus tinctorius*. Forest Science 22(1): 91-100; 1976.
16. Marx, D.H.; Bryan, W.C.; Davey, C.B. Influence of temperature on aseptic synthesis of ectomycorrhizae by *Thelephora terrestris* and *Pisolithus tinctorius* on loblolly pine. Forest Science 16:424-431; 1970.
17. Minore, D. Shade benefits Douglas-fir in Southwest Oregon cut-over area. Tree Planters' Notes 22(1):22-23; 1971.
18. Neter, J.; Wasserman, W. Applied linear statistical models. Homewood, IL: Richard D. Irwin, Inc.; 1974: 407-408.
19. Nie, N.H,; Hull, C.H.; Jenkins, J.G.; Steinbrenner, K.; Bent, D.H. Statistical Package for the Social Sciences, second edition. 428 p. 1975.
20. Nie, N.H.; Hull, C.H. SPSS Update 7-9. New York: McGraw-Hill Book Co.; 1981; 26 p.
21. Owston, P.W.; Stein, W.I. Survival, growth, and root form of containerized and bare-root Douglas-firs and noble firs seven years after planting. In: Eerden, E.V.; Kinghorn, J.M. (eds.). Proceedings, Root form of planted trees symposium. Jt. Rep. 8. Victoria, BC: British Columbia Ministry of Forests, Canadian Forestry Service; 1978: 216-221.
22. Ryker, R.A.; Potter, D.R. Shade increases first year survival of Douglas-fir seedlings. Res. Note 119. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 1970; 6 p.
23. Schramm, J.R. Plant colonization of black wastes from anthracite mining in Pennsylvania. Transactions of the American Philosophical Society 56:1-194; 1966.
24. Steele, R.G.D.; Torrie, J.H. Principles and procedures of statistics. New York: McGraw-Hill Book Co., 1960: 109-110.
25. Trappe, J.M. Selection of fungi for ectomycorrhizal inoculation in nurseries. Annual Review of Phytopathology 15:203-222; 1977.

Survival and Coverage by Several N_2-Fixing Trees and Shrubs on Lime-Amended Acid Mine Spoil

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Acid mine spoil was amended with agricultural-grade lime ($CaC0_3$) (0.0, 12.5, 25, and 39 tons per hectare) and planted with Alnus glutinosa *(European alder),* Caragana aborescens *(Siberian peashrub),* Elaeagnus umbellata *(autumn olive),* Myrica pensylvanica *(northern bayberry),* Robinia fertilis *'Arnot' (bristly locust),* Robinia pseudoacacia *(black locust), and* Shepherdia argentea *(silver buffaloberry). Addition of lime caused significant linear increases in soil pH. To maintain a pH above 5.5, 39 metric tons per hectare were required because of the acidic nature of the mine spoil. Survival of plant material was greatest at the highest lime addition, although responses of individual species varied*. Elaeagnus umbellata, R. pseudoacacia, R. fertilis *'Arnot', and* A. glutinosa *appeared more tolerant of the harsh conditions. Total coverage and growth (projected biomass) was proportional to the amount of added lime for all species except* R. pseudoacacia, R, fertilis *'Arnot', and* M. pensylvanica*. The two* Robinia *species showed no response above 25 tons per hectare and* M. pensylvanica*. The two* Robinia *species showed no response above 25 tons per hectare and* M. pensylvanica *performed best at lower pH.* Tree Planters' Notes 37(3):27-31; 1986.

Strip-mine spoil banks can be one of the most hostile environments for plant establishment and development, generally because of extremes in pH, texture, and slope (13). Soil temperature, low water-holding capacity, and nutrient status can also be limiting factors but are generally correctable.

In midwestern and eastern mine spoils, pH values as low as 2.2 have been recorded (1). Extreme acidity is generally the result of acid clays, sandstones, or shale or of the oxidation of pyrite to sulfuric acid (17, 18). Lime treatments may provide only short-term increases in pH because of the constant oxidation of sulfur-containing compounds (5, 19). Spoils with pH values less than 4.0 are generally considered toxic to most plants (18, 19).

Struthers and Vimmerstedt (15) believed that reclamation of mine sites would be more rapid and successful if methods were directed toward basic land improvement rather than superficial landscaping. They held little promise in the search for more tolerant plant species. A large number of species trials have been conducted on disturbed land over the years (7-9, 14, 15). Criteria for selecting plants for mine reclamation include suitability for drastic site conditions (pH, drought, low fertility, etc.) and the ability to rapidly develop long-term site cover. Additional considerations are soil enrichment, wildlife cover, and economic productivity (13, 14).

A number of woody nitrogen-fixing species have shown promise or are currently used for mine reclamation. These include *Alnus glutinosa* (L.) Gaertn. (3, 11, 13), *Elaeagnus angustifolia* L. (14), *E. commutata* Bernh. ex Rydb. (14), *E. umbellata* Thunb. (10, 13, 14), *Robinia fertilis* Ashe. (13, 16), and *R. pseudoacacia* L. (3, 4, 7-10, 12). Nitrogen-fixing trees and shrubs offer excellent possibilities for low maintenance and potentially productive perennial mineland cover. Some site amendment will be necessary to ensure survival of plants, and selection of species must be coordinated with site conditions. Organic matter has been shown to increase and surface temperatures to moderate as trees and shrubs increase in size (2).

This moderating effect favors establishment of other, less tolerant species. Nitrogen-fixing woody species could be combined with grass-legume cover crops and possibly other long-term forest crops to develop a total plant community on disturbed sites.

Materials and Methods

The site of the study was a surface coal mine in southwest Indiana that had been returned to original contour and was being revegetated. Several pH samples were taken to ensure as nearly a consistent pH as possible for the experimental areas. Lime requirements were determined using the SMP buffer pH method (6). Because of the extremely low initial pH (2.85) and the acid nature of mineland spoils, SMP lime rates were 0, 12.5 (low), 25 (medium), and 39 (high) metric tons of $CaC0_3$ (agricultural-grade limestone) per hectare. Treatments were spread by hand and disked to a depth of 15 to 20 centimeters in perpendicular directions. Each plot (11 by 5.8 meters) was replicated four times.

Plots were planted with ten 1- to 2-year-old seedlings of *A. glutinosa*, *Caragana arborescens* L., *E. umbellata*, *M. pensylvanica* Lois., *R. fertilis* 'Arnot'. *R. pseudoacacia*, and *Shepherdia argentea*. Plants were nodulated at the time of planting, and legumes were reinoculated with commercial *Rhizobium* preparations. Seedlings were planted at a spacing of 90 by 120 centimeters on April 26, 1977. Soil was tested and plant survival observations were taken on May 19, June 14, August 23, and September 21, 1977, and May 5, and July 7, 1978. Soil pH was determined using 2.5:1 (water/soil).

Projected biomass was determined by multiplying the average dry weight of plant tops from a maximum of five representatives from each replicate by the number of survivors in a given species. Dry weights of tops were measured after drying at 80 °C for 5 days.

Results and Discussion

The addition of lime ($CaC0_3$) to acid strip-mine spoil raised the pH markedly, with the highest pH being achieved within 30 days of application (fig. 1). It required 39 tons per hectare to achieve a pH of 6.5 and maintain a pH of approximately 5.75 at 15 months after application. The medium and low lime treatments resulted in an increase in pH up to 6.1 and 5.0 initially, but these pH values declined to 4.8 and 3.5 after 15 months. Without lime, pH remained low (2.9).

Additions of lime maintained a relatively steady pH on acid mine spoils when amounts were adequate to overcome the constant

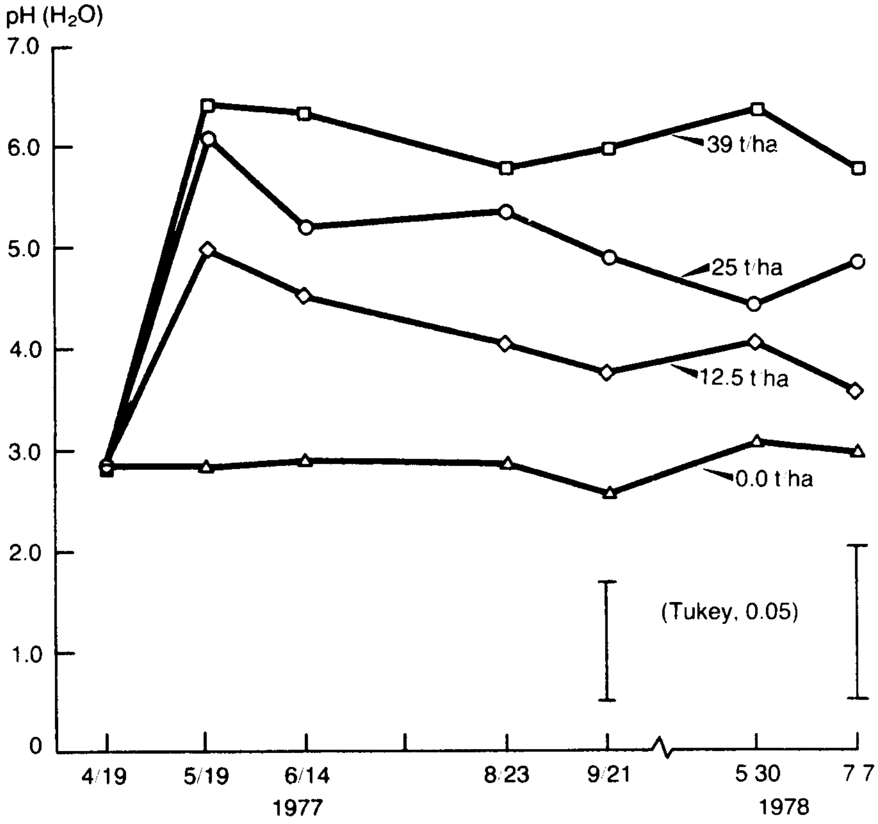

Figure 1—*Increased soil pH as a result of lime ($CaCO_3$) addition. $CaCO_3$ amendment is given to metric tons per hectare. Vertical bar represents significant mean separations (Tukey-hsd, 5%).*

leaching of acid from the parent material. Lime applications that would be adequate for normal soils were able to provide only short-term pH adjustment against the constant acid leaching as indicated by the decline in pH values of low and medium lime treatments (fig. 1). The pH of 5.75 resulting from the high lime treatment is adequate for growth of most plants. Although pH might be expected to decline somewhat over time, additions of organic matter by the plants would aid the soil's buffering capacity.

Table 1—*Effects of lime ($CaCO_3$) supplementation on survival nitrogen-fixing species planted on acid mine spoil*[1]

	Percent survival				
Species	0.0	Low lime (12.5 t/ha)	Medium lime (25.0 t/ha)	High lime (39.0 t/ha)	Average
Elaeagnus umbellata	0 c	53 b z	55 ab z	82 a z	48 z
Robinia fertilis 'Arnot'	21 b	37 ab z	60 a z	63 a yz	46 z
Shepherdia argentea	0 c	26 bc z	53 ab z	87 a z	42 yz
Alnus glutinosa	0 c	43 ab z	28 bc yz	77 a z	37 yz
Robinia pseudoacacia	9 b	30 ab z	38 ab z	63 a yz	35 yz
Caragana arborescens	0 c	17 bc z	30 b yz	60 a yz	27 yz
Myrica pensylvanica	0 a	33 a z	13 a y	27 a y	18 y

[1] Data collected on July 7, 1978. Mean separations by Tukey-hsd, 5%. Values within a row (a, b, c) or column (z or y) followed by different letters differ significantly.

Plant survival. Addition of increasing amounts of limestone to acidic mine spoil had a 97.2 percent linear correlation to survival of all species approximately 1 year after planting. This concurs with the suggestion by Struthers and Vimmerstedt (15) that reclaimed mineland spoils be modified to obtain good plant survival rates. However, some species appear more tolerant of the harsh conditions than others.

Robinia fertilis 'Arnot' and *R. pseudoacacia* were the only species to survive without the addition of lime (table 1); however, the individuals failed to grow and were essentially the same size as when planted. Survival rates of *R. fertilis* 'Arnot' and *R. pseudoacacia* (table 1), as with all species, were significantly increased with the addition of lime, but there was no statistical difference between higher and lower levels.

Survival of *E. umbellata* was high at all levels of lime addition (table 1). The 82 percent at the high lime treatment was greater than the 53 and 55 percent at the medium and low lime treatments, but not statistically because of variation within the replicates. Survival of *A. glutinosa* was greater at the high lime treatments (table 1) but was not statistically distinguishable from that at low lime treatments. The percent survival at the medium lime treatments was significantly less than at high but not at low lime treatment. *Caragana arborescens* and *S. argentea* responded to the high lime treatment with significantly greater survival (table 1). The low and medium lime treatments resulted statistically in the same low survival rates.

Survival of *M. pensylvanica was* poor at all lime additions (less than 50 percent) and was best, although not statistically, at the low lime treatment (table 1).

There was significant difference in the combined survival of all species at all lime levels (table 1). Poorest overall performance was by *M. pensylvanica* and best overall survival was by *E. umbellata*, *R. fertilis* 'Arnot', and *S. argentea*. Response of individual species varied with lime additions as demonstrated by the individual survival data. The highest lime application rate (pH 5.75) resulted in the highest survival rates for all species but *M. pensylvanica* (table 1). Survival of *S. argentea* was greatest but not statistically better than that of other species except *M. pensylvanica.*

Robinia fertilis 'Arnot', *E.* umbellata, and *S. argentea* survived best at the medium lime treatment (pH 4.8) (table 1) but were not significantly different from other species, except *M. pensylvanica.*

Regardless of the care taken to find homogeneous sites for the study, some variation with the replicates prevented detection of discrete statistical differences among the majority of the species at given treatment levels or differences within the responses of individual species to lime additions. *Elaeagnus umbellata*, *R. fertilis* 'Arnot', and *R. pseudoacacia* performed well at all amended pH levels. Insect infestation was noted on *R. pseudoacacia* the first season after planting and was more severe during the second season. There was no insect damage evident on any other surviving species in the study.

Projected biomass. Projected biomass is meant to provide an index of growth and ground cover associated with species and treatments within this study. It was calculated from actual dry matter data for species within a replicate and/ or top dry weights of representative samples multiplied by the number of individuals surviving within the replicate. It is expressed as grams per square meter.

The mean biomass for all species had a *97* percent linear correlation with lime additions (table *2). Elaeagnus umbellata* achieved the greatest projected biomass of any species at all lime additions and showed a linear correlation of *95* percent for increased growth with increasing lime level (table *2).*

Shepherdia argentea and *A. glutinosa* showed *99* and *97* percent linear correlations, respectively, between projected biomass accumulation and lime additions (table *2). Alnus glutinosa* responded dramatically to the high lime treatment *(39* tons per hectare).

Robinia pseudoacacia and *R. fertils* 'Arnot' (table *2)* responded nearly identically in projected biomass development with lime additions. Both provided minimal cover on unamended sites, responded dramatically to the medium lime treatment, and declined slightly in the high lime treatment.

Table 2—*Effects of lime supplementation on mean projected biomass of nitrogen-fixing species planted on acid mine spoil*[1]

	Mean projected biomass (g/m^2)				
Species	0.0	Low lime (12.5 t/ha)	Medium lime (25.0 t/ha)	High lime (39.0 t/ha)	*r*
Elaeagnus umbellata	—	16.9 b	73.0 a	79.0 a	0.95
Robinia fertilis 'Arnot'	3.0 b	4.3 b	36.0 a	30.2 a	—
Robinia pseudoacacia	0.1 b	3.0 b	38.4 a	32.7 a	.86
Alnus glutinosa	—	8.8 b	10.4 b	23.7 a	.97
Caragana arborescens	—	4.2 c	6.2 b	18.7 a	.94
Shepherdia argentea	—	8.2 a	11.8 a	19.4 a	.99
Myrica pensylvanica	—	11.2 a	2.0 a	2.9 a	—
All species	0.41 b	8.1 b	25.4 a	29.5 a	.97

[1] Mean separation by Tukey-hsd, 5%. Values within a row followed by different letters differ significantly. Correlation coefficients (*r*) less than 0.90 are not listed.

Myrica pensylvanica provided greater growth and cover at the lowest lime additions *(12.5* tons per hectare) (table *2).* However, there was statistically no difference between treatment means.

Conclusions

Applications of agricultural-grade limestone had significant effects on the pH of acid strip-mine spoil and on the survival and projected biomass of the legume and nonlegume nitrogen-fixing species tested. Liming is the minimum site modification necessary for plant survival and growth. The pH of the spoil after all lime treatments dropped steadily, and only the *39* tons per hectare treatment maintained the pH above *5.0.* Constant acid leaching from the parent material necessitates the use of massive quantities of neutralizing materials. Split or additional applications may prove necessary, if feasible, to maintain pH within plant tolerance ranges on some sites.

Lime applications or pH increases were required for the survival of most and the growth of all species. Survival was greatest at the highest lime applications; however, response of individual species varied. *Elaeagnus umbellata*, *R. pseudoacacia*, *R. fertilis* 'Arnot', and *A. glutinosa* appeared to be more tolerant of the harsh conditions. Survival was generally good to fair, even at the lowest lime treatment, which resulted in spoil with a pH below the 4.0 considered toxic for most species. *Caragana arborescens* and *S. argentea* appeared to survive best if pH can be maintained near 6.0. *Myrica pensylvanica* survived better at lower lime applications, but its survival rate was generally poor at all treatment levels.

Total coverage and growth, as measured by projected biomass, was proportional to lime applications in all species except *R. pseudoacacia*, *R. fertilis* 'Arnot', and *M. pensylvanica*. *Myrica pensylvanica* performed best at lower pH and the two *Robinia* species showed no response at applications above 25 tons per hectare (pH 4.8).

Elaeagnus umbellata seemed to be a superior plant for the amended study site. *Robinia pseudoacacia*, *R. fertilis* 'Arnot', and *A. glutinosa* performed admirably and warrant inclusion in a total plant community. *Shepherdia argentea* and *C. arborescens would* appear more suitable on more extensively amended or less severe sites. Although survival of *M. pensylvanica* was low, its growth at low pH may warrant consideration in certain situations.

Although *R. pseudoacacia* is the most frequent nitrogen-fixing member of current plant communities on disturbed sites, it is not necessarily an ideal plant. Insect infestation had weakened the growth habit of the plants. While tolerance and survival may warrant continued usage, certain limitations for long-term and economic considerations should be weighed in comparison to other species.

Literature Cited

1. Armiger, W.A.; Jones, J.N.; Bennett, O.L. Revegetation of land disturbed by stripmining of coal in Appalachia. ARS-NE-71. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service; 1978. 38 p.
2. Boyer, S.G.; Mertz, R.W. Tree species recommended for strip-mine plantations in western Kentucky. Tech. Pap. 160. Columbus, OH: Gent. Forestry Experiment Station; 1950. 32 p.
3. Brown, J.H. Height growth prediction for black locust on surface-mined areas. In: Proceedings, revegetation and economic use of surface-mined land and mine refuse symposium; Pipestem, WV. 1973: 26-28.
4. Brown, J.H. Height growth prediction for black locust on surface-mined areas in W. Virginia. Bull. 619. Morgantown, WV: West Virginia University Agricultural Experiment Station; 1973.
5. Carpenter, P.L.; Hensley, D.L. Utilizing N2-fixing woody plant species for distressed soils. In: Symposium, nitrogen fixation in actinomycete-nodulated plants. Petersham, MA: Harvard Forest, Harvard University; 1978.
6. Council on Soil Testing and Plant Analysis. Handbook on reference methods for soil testing. Athens, GA; 1974: 22-27.
7. Davis, G.; Melton, R.E. Trees for graded stripmine spoils. Res. Pap. 32. University Park: Pennsylvania State University Forestry School; 1963. 4 p.
8. Dean, F.W. The reclamation of stripped coal lands. Journal of Forestry 23:677--682; 1925.
9. Den Uly, D. Survival and growth of hardwood plantations on strip-mine spoil banks of Indiana. Journal of Forestry 60:603-606; 1962.
10. Finn, R.F. Ten years of strip-mine reforestation research in Ohio. For. Mgmt. Res. Rep. Athens, OH: Central States Forest Experiment Station; 1955.
11. Funk, D.T. Growth and development of alder plantings on Ohio strip-mine banks. In: Hutnik, R.J.; Davis, G., eds. Ecology and reclamation of devastated land, Vol. 1. New York: Gordon and Breach; 1973: 483-491.
12. Limstrom, G.A. Forestation of strip-mined land in the central states. Agric. Handbk. 166. Washington, DC: U.S. Department of Agriculture; 1960. 74 P.
13. Grandt, A.F. Species trials on strip mine area. In: Symposium, disturbed land reclamation and use in the Southwest. Tuscon, AZ: University of Arizona; 1975.
14. Plass, W.T. An evaluation of trees and shrubs for planting surface-mine spoils. Res. Pap. NE-317. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1975.8 p.
15. Struthers, P.H.; Vimmerstedt, J.P. Rapid strip mine reclamation. Ohio Report 50:85-87; 1965.
16. Sutton, P. Soil Conservation Service plant materials tested at the eastern Ohio Resource Development Center on coal mine spoil bank. Spec. Rep. Wooster, OH: Ohio Agricultural Research and Development Center; 1968.6 p.
17. Sutton, P. Restoring productivity to coalmine spoil banks. Ohio Report 55(4):61-63; 1970.
18. Sutton, P. Reclamation of toxic coalmine spoil banks. Ohio Report 55(5):99-100; 1970.
19. Sutton, P.; Vimmerstedt, J.P. Treat strip mine spoils with sewage sludge. Ohio Report 58(6):121-123; 1973.

Determination of Scalps per Unit Area Produced by the Bracke Scarifier[1]

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The Bracke scarifier mechanically produces scalped planting sites. Considerable error can result from small variations in planned distances between passes. The features of the scarifier and its operation are described, and a table that can be used for quick determinations of the distance between passes of the equipment is included. Tree Planters' Notes 37(4):29-30; 1986.

The Bracke scarifier (figure 1) is manufactured in Sweden and is used for approximately 70 percent of the mechanized site preparation done in that country. The equipment has been used in Canada since the early 1970's. Hand seeding in Canada with the device is discussed by Winton and Schneider (3).

The Bracke was introduced to the Lake States in 1978 and its use is described by Cutler (1) and Nelson and Oldford (2). The equipment has gained in popularity as evidenced by its use on approximately 5,000 acres in Minnesota in 1985.

The Bracke is pulled by a variety of forwarders with horsepower ranging from 90 to 210.

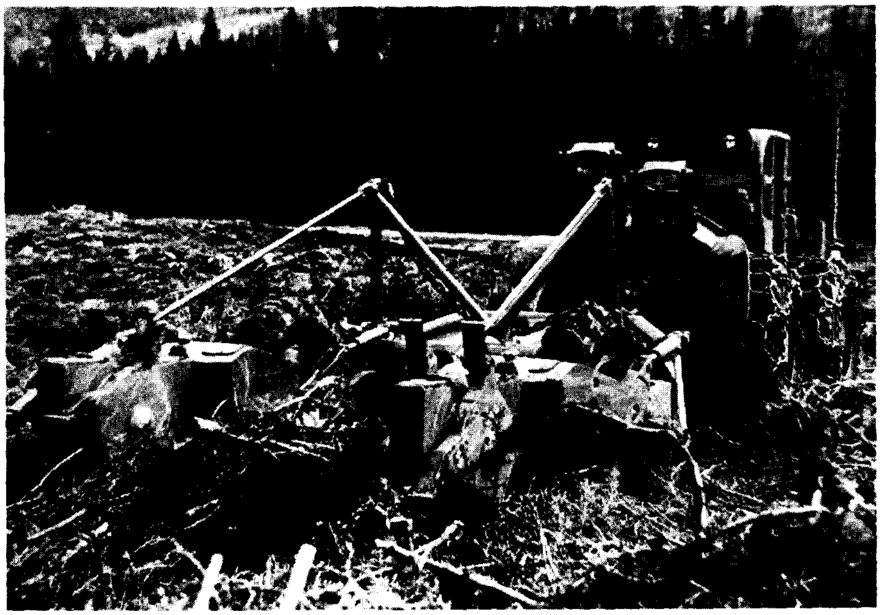

Figure 1—*The Bracke scarifier.*

The device has two scarifying wheels, each of which has four sets of scarifying teeth. The scarifying wheels are chain driven from the rubber tires on the Bracke. The scarifying teeth rotate in the same direction as the tires but turn slower so that they drag in the soil and scarify a microsite or scalp for planting or seeding.

Each pass of the scarifier produces two rows of scalps 6.6 feet (2.0 meters) apart (measured between scalp centers). Within rows, spacings of 6.6 feet (2.0 meters), 8.2 feet (2.5 meters), or 9.8 feet (3.0 meters) between scalps are possible using axle gears with 19, 17, or 15 teeth, respectively.

The Bracke is a durable machine that can be used in rugged terrain, and on relatively steep slopes, with a winch cable. It prepares intermittent scalps rather than a continuous row. This minimizes erosion because no water travel path is created. An often cited advantage with the equipment is that it lays out the planting site and increases speed and efficiency by providing a pattern that tree planters can follow. This also makes it easier for forest managers to plan and properly allocate the number of trees for planting on a unit area basis.

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Table 1—*Scalps per unit area for various axle gear settings (which determine distance between scalp centers) and various distances between passes with the Bracke Scalper*

Distance between passes (ft)				Distance between passes (m)			
Gear 19 (6.6 ft)	Gear 17 (8.2 ft)	Gear 15 (9.8 ft)	No. of scalps/acre	Gear 19 (2.0 m)	Gear 17 (2.5 m)	Gear 15 (3.0 m)	No. of scalps/ha
27.3	20.4	15.8	400	8.2	6.1	4.7	1000
23.5	17.4	13.3	450	7.3	5.4	4.1	1100
20.4	14.9	11.3	500	6.5	4.7	3.6	1200
17.9	12.9	9.7	550	5.8	4.2	3.2	1300
15.8	11.3	8.3	600	5.2	3.8	2.8	1400
14.1	9.9	7.1	650	4.7	3.4	2.5	1500
12.6	8.7	6.1	700	4.3	3.0	2.2	1600
11.3	7.7	5.3	750	3.9	2.7	1.9	1700
10.2	6.8	4.5	800	3.6	2.5	1.7	1800
9.2	6.0	3.9	850	3.3	2.2	1.5	1900
8.3	5.3	3.3	900	3.0	2.0	1.3	2000
7.5	4.7	—	950	2.8	1.8	1.2	2100
6.8	4.1	—	1000	2.6	1.7	1.0	2200
6.1	3.6	—	1050	2.4	1.5	—	2300
5.6	3.1	—	1100	2.2	1.3	—	2400
5.0	—	—	1150	2.0	1.2	—	2500
4.5	—	—	1200	1.9	1.1	—	2600
—	—	—	—	1.7	1.0	—	2700
—	—	—	—	1.6	—	—	2800
—	—	—	—	1.5	—	—	2900
—	—	—	—	1.3	—	—	3000

The critical factor in attaining the desired number of scalps or planting spots per unit area is maintaining proper distance between passes. Table 1 provides a quick reference to determine the number of scalps that will be made with varying distances between passes. The data in the table were generated with the following assumptions.

1. A four-toothed mattock wheel is used.
2. The initial pass is made at an edge of the site.
3. Passes are longitudinal and not circular in pattern.
4. Width of a pass is measured from center to center of adjacent scalps.
5. Distance between passes is measured from center to center of scalps on outside rows.
6. All scalps are plantable.

Maintaining the proper distance between passes is difficult under field conditions. However, even small variations in distance between passes can result in considerable error in number of scalps per unit area. For example, a variation of 1 foot between passes results in a difference of about 50 scalps per acre (table 1). Similarly, one-third of a meter variation in distance results in a difference of more than 100 scalps per hectare. In order to calculate the number of trees needed for planting, the operator and landowner should determine the average spacing between passes and assess the number of plantable scalps, which may vary with site conditions.

Literature Cited

1. Cutler, Richard W. Site preparation with the Bracke scarifier. Proceedings, Artificial Regeneration of Conifers in the Upper Great Lakes Region, 1982. Houghton, MI: Michigan Technological University; 1982: 227-229.
2. Nelson, David E.; Oldford, Gordon C. Swedish Bracke cultivator: site preparation and seeding. Tree Planters' Notes 30(3):24-26; 1979.
3. Winston, D.A.; Schneider, G. Conifer establishment by hand seeding on sites prepared with the Bracke cultivator. Rep. 0-X-255. Sault Ste. Marie, ON: Canadian Forestry Service, Great Lakes Forest Research Centre; 1977. 11 p.