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Geotech® at Westvaco

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Nursery bed stabilization to reduce seed and seedling losses due to water and wind erosion has long been a subject of trial and error. Due to strong winds at planting time, and occasional heavy spring rains, we incorporated Geotech into our 1987 cultural operations. We were excited about the stabilization qualities of this water-resistant co-polymer resin. Tree Planters' Notes 40(2): 3-4 ; 1989.

Westvaco has used the full gamut of different mulches and even no mulch. Years ago pine straw was used, and it probably remains one of the most efficient stabilizers of seedling beds. However, due to cost, availability, time, etc., we moved on to what we thought were better things.

We used hydromulch for several years and experimented with every type of hydromulch we could purchase. Hydromulch did a satisfactory job with wind erosion, but left a lot to be desired on water erosion. It also contributed to sand splash, and bred a hybrid ailment we refer to as "sanulch." Sanulch is a combination of sand and mulch forming on the young seedlings' stems and needles, resulting in slow growth and/or mortality. We tried no mulch after seeding and had surprisingly good results with 4 years of data. Planting deeper and planting early seems to be the key.

Bed washing due to heavy rains remained a problem. We then tried pine nuggets. This material has admirable qualities, but it also comes with a high price tag in our area, costing four times the price of sawdust. Even with nuggets, some minor bed edge deterioration was still evident.

This brings us to Geotech® (Borden, Inc.) a water-resistant co-polymer emulsion designed for control of various types of surface erosion (1). Geotech cures to an invisible film that forms a crust with the surface soil. This crust prevents slope or surface deterioration due to wind, rain, or irrigation.

Design and Applications

We modified our 800-gallon Finn Hydromulcher to apply Geotech. We took the nursery bed splashboard off and built a double-hinged triple-spray boom capable of spraying three beds at a time. The boom line itself is 1-inch galvanized pipe with fifty-one #8020 tee-jet nozzles on 12-inch centers in a diamond pattern with one cut-off valve for each section and a pressure gauge on each hinged section end.

Spraying pressure should be maintained at approximately 40 pounds/square inch. Nozzles should be used without screens. We also disarmed the paddle wheel agitator to keep foaming to a minimum. The bypass continued to operate, keeping the solution in suspension. You must have some agitation continuously. If you use a hydromulcher that has any age associated with it, be sure you sandblast or clean the inside of the tank thoroughly, and paint. If you do not, you will spend many hours in unproductive nozzle cleaning.

Like everyone else, we keep changing and modifying our operations and equipment. By the time you read this report, we will probably be using a hydraulic pump or jack shaft PTO to drive our pump rather than the four-cylinder gasoline engine now on the unit.

Geotech is somewhat messy on equipment if not cleaned off immediately. It adheres to the air intake screen, etc., making the engine run hot. We also plan to use drop nozzles instead of stationary nozzles on bed edges. Installing a line filter would be beneficial.

Our primary objective last year was to control wind erosion in our most wind-vulnerable fields. We applied Geotech at two rates: at approximately 1:12, (40 gallons Geotech mixed with 480 gallons water) and 1:9 (55 gallons Geotech mixed with 495 gallons water). The total volume

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of solution should be about 550 gallons/acre regardless of Geotech rate. The higher rate retained the bed structure for a longer period of time. We plan a compromise between the two this year.

We mix Geotech in the field using a 4-inch quick-release water line from the irrigation pump and a transfer pump in 55-gallon drums, which are loaded on a 5-ton flatbed truck. The transfer pump pulls Geotech directly out of the drums into the Finn machine. A screen attached to the intake line of the transfer pump acts as a filter. Fill-up, wash-off, and nozzle checks take about 10 minutes per load. We treat approximately 1½ acres per tank and spray at 3 miles/hour, immediately after seeding on a bed with no mulch. We wait 2 hours before irrigating or applying herbicide to allow Geotech time to cure.

Summary

Geotech was applied on 75% of our seedbeds last year with very good results and will be applied on 100% this year. It did not affect germination nor bed temperatures, and seedling survival increased several percentage points. It also eliminated sand splash. At this point, there appear to be no ill effects on soil characteristics. We will continually monitor for such effects.

A few words of caution: *be careful of seed placement!* Seed should be covered lightly with approximately ¼ inch of soil. This is somewhat deeper than some of us have planted in the past. Before applying Geotech, make sure the bed is moist—not wet and not dry. Ground temperature should be 55 °F or above. If applied under the correct conditions, it is possible to get ¼-inch penetration, with ? inch being the norm. In conclusion, Geotech was superior to sawdust for wind and water erosion in our nursery. This is based on only 1 year's results, but we plan to stay with Geotech applications in the future.

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Plant Nutrients Removed by Nursery Stock

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*Nutrient concentrations and biomass of roots, stems, and needles were determined for 2 + 0 seedlings of four conifer species: red pine (*Pinus resinosa *Ait.), eastern white pine (*Pinus strobus *L.), white spruce* (Picea glauca *(Moench) Voss), and Norway spruce* (Picea abies *(L.) Karst.). The pines consumed larger amounts of nitrogen, phosphorus, and potassium than did the spruces. Consumption of fertilizer equivalents per acre was in the order of red pine > eastern white pine > white spruce > Norway spruce.* Tree Planters' Notes 40(2):8-11; 1989.

Nurseries support one to two million seedlings per acre. Fertilizers must be added to produce nutritionally well balanced and high-quality seedlings that survive when outplanted. To gather data on the concentration of nutrients in coniferous tissue, 2-year-old seedlings were collected from the Wilson State Nursery, located near Boscobel, WI. The soil in this nursery is developed in quartsitic sandy river terrace of poor fertility. Improvement in soil fertility over the years was accomplished by the addition of peat, fermented sawdust compost, green manure, and N-P-K fertilizers applied broadcast, as top dressing, and as nutrient solutions. This has resulted in production of high-quality seedlings.

Coniferous seedlings of four different species grown at this nursery were analyzed for major, secondary, and micronutrients in the needles, stems, and roots. The amounts of the primary nutrients removed by the stock were then calculated. Analyses of soil samples from beds supporting the different species are used to indicate the adequacy of maintenance fertilizer applications applied in past years.

Materials and Methods

Two composite soil samples consisting of fifteen 6-inch cores were collected from individual beds each of which supported four different species: 2 + 0 red pine, eastern white pine, white spruce and Norway spruce. One-hundred seedlings of each of the species were randomly sampled and analyzed for morphological and chemical characteristics (fig. 1).

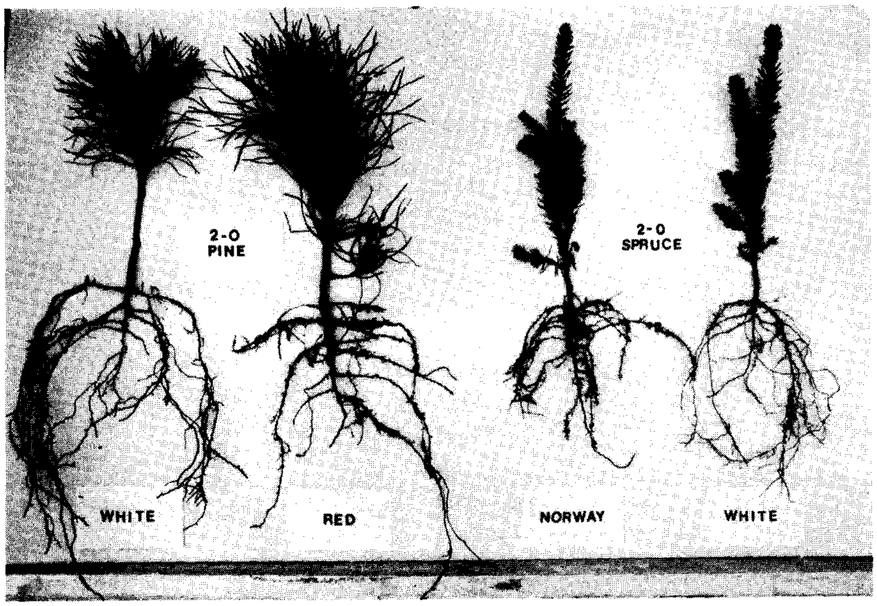

Figure 1—*Two-year-old coniferous stock (from left to right): eastern white pine, red pine, Norway spruce, white spruce* (Wilson State Nursery, WI).

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Dr. R. B. Corey, Department of Soil Science, University of WisconsinMadison, made helpful suggestions and reviewed the manuscript.

The soil samples were dried in a forced-air oven at 70 °C and were then analyzed for fertility factors according to the methods outlined in Wilde et al. (4). The seedlings were first measured for morphological characteristics, then dried in a forced-air oven at 70 °C. Dry weights of tops and roots were measured and the samples were ground and analyzed for total mineral content by inductively coupled plasma emission spectroscopy (3). Total nitrogen was determined by the Kjeldahl method (2).

Results and Discussion

Soil analyses (table 1) revealed that most of the fertility factors in this area were ideal, with pH ranging from 5.5 to 5.6; silt plus clay at 9 to 11%; organic matter, 1.98 to 2.55%; available phosphorus, 153 to 168 pounds/acre P_2O_5; and exchangeable calcium and magnesium, 2.10 to 2.75 and 0.49 to 0.72 mE/100 g, respectively. Available potassium was 84 to 120 pounds/acre K_2O, which is lower than the optimum; this low level is attributed to uptake of potassium by seedlings as well as leaching losses that can occur in sandy soil.

The size of planting material is seldom correlated with its potential performance. More significant criteria are provided by the ratios of height of trees to stem diameters and of tops to roots. The height-diameter ratio in pines ranged from 4.05 to 4.58 and in spruces from 7.80 to 8.49. The top-root ratio in pines ranged from 2.12 to 2.76 and for spruces from 2.98 to 3.61. Both ratios are in acceptable ranges (table 2). The resistance of planting stock to adverse climatic influences and fungal diseases is also dependent on its concealed attributes, which include an adequate and well-balanced internal supply of macronutrients as well as micronutrients.

The nutrient concentrations of the roots, stems, and needles in four coniferous species are listed in table 3. No deficiencies or excesses of either major elements or microelements were apparent. Table 4 presents the uptake of N, P, and K per seedling, which varies with the biomass of each species as well as nutrient concentration. Uptake of N, and P followed the order of eastern white pine > red pine > Norway spruce > white spruce. Uptake of potassium followed the order of red pine > eastern white pine > Norway spruce = white spruce.

Table 1—*Fertility factors of soil supporting 2 + 0 conifers*

Species	pH	Silt clay (%)	Organic matter (%)	Available nutrients (lb/ac)		Exchangeable nutrients (mEq/100 g)	
				P	K	Ca	Mg
Red pine	5.5	11	2.38	163	120	2.50	0.55
Eastern white pine	5.6	9	2.55	158	120	2.75	0.49
White spruce	5.5	10	2.55	168	84	2.10	0.55
Norway spruce	5.6	10	1.98	153	108	2.10	0.72

Table 2—*Morphological characteristics of average 2 + 0 conifer seedlings*

Properties of stock	Red pine	Eastern white pine	White spruce	Norway spruce
Height (cm)	24	21	30.5	31
Root length (cm)	51.5	45	35.0	29.5
Stem diameter (mm)	5.93	4.59	3.91	3.65
Weight of seedlings (g)	8.81	7.68	5.03	5.03
Weight of tops (g)	6.47	5.22	3.94	4.08
Weight of foliage (g)	4.44	3.33	1.88	2.08
Weight of roots (g)	2.34	2.46	1.09	1.37
Height/diameter ratio	4.05	4.58	7.80	8.49
Top/root ratio	2.76	2.12	3.61	2.98

Table 3—*Concentration of nutrient elements in 2 + 0 coniferous seedlings*

	Conc. (%)						Conc. (ppm)					
Plant part	N	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al
Red pine												
N	1.44	0.22	0.85	0.31	0.15	0.11	81	7.9	434	70	3.1	86
S	0.78	0.14	0.44	0.25	0.14	0.06	67	6.9	232	131	4.3	169
R	0.50	0.10	0.29	0.15	0.08	0.06	47	5.5	113	595	3.0	877
Eastern white pine												
N	1.98	0.25	0.73	0.50	0.19	0.17	94	9.4	262	90	3.6	75
S	0.92	0.22	0.81	0.24	0.18	0.13	90	9.1	145	145	7.2	168
R	0.62	0.14	0.28	0.21	0.09	0.07	72	6.2	78	782	3.2	1126
White spruce												
N	1.68	0.28	0.69	0.95	0.18	0.14	109	8.5	457	163	3.3	148
S	0.77	0.16	0.54	0.45	0.12	0.06	88	7.8	166	182	4.8	143
R	0.68	0.14	0.32	0.31	0.09	0.06	71	7.1	84	777	2.9	1084
Norway spruce												
N	1.84	0.26	0.70	0.83	0.20	0.12	55	6.8	221	125	3.5	89
S	0.67	0.16	0.47	0.40	0.14	0.06	74	8.1	100	95	4.6	93
R	0.74	0.09	0.26	0.29	0.09	0.06	45	6.6	62	982	2.8	1290

N = needles, S = stem, R = roots.

Table 4—*Total uptake per seedling of N, P, and K by average 2 + 0 coniferous seedlings*

Species	Seedling weight (g)	Nutrient uptake (mg/seedling) N	P	K
Red pine	8.8	92	14.9	54
Eastern white pine	7.7	98	15.9	45.9
White spruce	5.0	55	10.1	27.5
Norway spruce	5.5	61	9.8	27.6

Table 5—*Uptake of N, P, and K per unit area at standard planting density of seedling beds*

		Nutrient uptake					
		N		P		K	
Species	Density/ft²	lb/ac	kg/ha	lb/ac	kg/ha	lb/ac	kg/ha
Red pine	29	256	286	42	46	150	168
Eastern white pine	26	245	274	39	44	115	128
White spruce	35	185	207	34	38	92	103
Norway spruce	26	152	170	24	27	69	77

Table 5 lists the uptake of N, P, and K by coniferous species per unit area at standard planting densities for the different species. Uptake of N, P, and K per unit area followed the order of red pine > eastern white pine > white spruce > Norway spruce. Table 6 presents the equivalent amounts of common commercial fertilizer materials consumed by 2 + 0 coniferous species over a 2-year period.

In conclusion, seedling analysis is an important tool in guiding fertilization practices. The results obtained from the analyses can be used to estimate maintenance fertilizer applications more accurately based on the amounts removed by different species and to design the most effective fertilizer program for the production of tree planting stock.

Table 6—*The equivalent amounts of N, P, and K fertilizers consumed by 2 + 0 coniferous species*

	Fertilizer consumed (lb/ac)		
Species	$(NH_4)_2SO_4$ (21 – 0 – 0)	Na_3PO_4 (0 – 45 – 0)	K_2SO_4 (0 – 0 – 50)
Red pine	1219	215	360
Eastern white pine	1166	199	276
White spruce	880	174	221
Norway spruce	724	122	166

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Development of Ectomycorrhizae on Container-Grown European Larch

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*Container-grown European larch (*Larix decidua *Mill.) were inoculated at sowing with mycelial cultures of eight ectomycorrhizal fungi. Inoculated and uninoculated seedlings were treated with standard and reduced levels of complete fertilizer and fungicides in two experiments. Only seedlings inoculated with* Hebeloma *crustuliniforme and* Laccaria laccata *developed significant ectomycorrhizae. Ectomycorrhizal plants were generally smaller than uninoculated seedlings. Standard fertilization reduced ectomycorrhizal development, stimulated shoot growth, and increased shoot-root ratios. Reduced applications of DCNA (Botran) and benomyl (Benlate) may permit ectomycorrhizal colonization of seedlings by selected fungal isolates.* Tree Planters' Notes 40(2) :12-17; 1989.

The use of ectomycorrhizal fungi as an aid in reforestation has been tested extensively in the nursery, greenhouse, and field in recent years (11, 16). Inoculation of seedlings with fungal isolates indigenous to the outplanting locale is usually beneficial (18). Past studies with container-grown European larch (*Larix decidua* Mill.) revealed erratic colonization by the ectomycorrhizal fungi *Suillus grevillei* (Kl.) Singer, *Suillus cavipes* (Opat.) Smith & Thiers, *Pisolithus tinctorius* (Pers.) Coker & Couch, and *Amanita muscaria* (L.: Fr.) Hooker (2, 3). Moreover, the benefit of ectomycorrhizae to the growth of European larch seedlings has not been clearly demonstrated (3).

Standard cultural practices used in producing container-grown European larch may not be suitable for ectomycorrhizal colonization (3). Factors such as source of fungal inoculum, growth medium fertility, and application of fungicides may significantly influence ectomycorrhizal development on seedlings (11, 16). For example, the frequent use of fungicides to control Botrytis infection of larch may influence ectomycorrhizal colonization (4, 5, 15).

The objectives of this study were to determine if (1) exotic and indigenous ectomycorrhizal fungi could be established on container-grown European larch seedlings through artificial inoculation and (2) standard applications of fertilizer and fungicides reduce seedling ectomycorrhizal colonization.

Materials and Methods

The fungal isolates used in this study (table 1) were collected and stored as stock culture using methods described by Molina (13). Vegetative mycelial inoculum for each isolate was grown aseptically using procedures described by Marx and Bryan (8).

A sterile peat moss—vermiculite–perlite mixture (2:1:1) was the potting medium. Sterilized four-cavity (175-cm^3 capacity) Rootrainers (Spencer—Le Maire Industries, Ltd., Edmonton, Alberta, Canada) were filled with either inoculated or uninoculated growth medium at proportions described below. European larch seeds from Czechoslovakia (NC-9948) were pregerminated and transplanted into container cavities 7 days after inoculation.

Experiment 1. Six fungal inoculation treatments (uninoculated control, *Cenococcum geophilum* (Fr.), *Suillus granulatus* (L.: Fr.) O. Kuntz, *S. grevillei* (Kl.) Singer, *S. luteus* (L.:Fr.) S.F. Gray, and *S. tomentosus* (Kauffm.) Singer, Snell & Dick); two fertilizer levels (standard and reduced); and two fungicide treatments (standard and reduced) were arranged in a split-plot design (fertilizer/ fungicide treatments were main plots and fungus treatments

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Table 1—*Sources and isolation dates of ectomycorrhizal fungus isolates used to inoculate container-grown European larch seedlings*

Fungal species	Isolate no.	Source and isolation data
Cenococcum geophilum (Fr.)	155	*Quercus alba,* Maryland, USA, isolated in 1973 by E. Hacskaylo from ectomycorrhiza and maintained as stock culture on MMN agar.
Suillus granulatus (L.:Fr.) O. Kuntz	263	*Pinus ponderosa,* Colorado, USA, isolated in 1980 by Z. Cornett from sporocarp tissue and maintained as stock culture on MMN agar.
Suillus grevillei (Kl.) Singer	10	*Pinus resinosa,* Minnesota, USA, isolated in 1984 by M. Palm and E. Stewart and maintained as stock culture on MMN agar.
Suillus luteus (L.:Fr.) S.F. Gray	244	*Pinus nigra,* Maine, USA, isolated in 1977 by W. Otrosina from sporocarp tissue and maintained as stock culture on MMN agar.
Suillus tomentosus (Kauffm.) Singer, Snell & Dick	1	*Pinus resinosa,* Minnesota, USA, isolated in 1984 by M. Palm and E. Stewart and maintained as stock culture on MMN agar.
Pisolithus tinctorius (Pers.) Coker & Couch	293	*Pinus taeda,* Georgia, USA, isolated in 1986 by D. Marx and maintained as stock culture on MMN agar.
Hebeloma crustuliniforme (Bull.) Quel.	166	*Pseudotsuga menziesii,* Washington, USA, isolated in 1981 by C. Bledsoe and maintained as stock culture on MMN agar.
Laccaria laccata (Scop.: Fr.) M.C. Cooke	813	*Pseudotsuga menziesii,* Oregon, USA, isolated in 1985 by R. Molina and maintained as stock culture on MMN agar.

MMN = modified Melin-Norkrans agar medium.

were subplots), with four replications on separate greenhouse benches. Each treatment combination was represented by 20 seedlings per replicate. One part of inoculum was thoroughly mixed with 20 parts of sterilized growth medium.

The standard fertilizer treatment was the operational fertilizer regime for European larch used at our facility, consisting of three weekly applications of Peters 20-20-20 (345 ppm N-P-K after dilution) plus Peters STEM micronutrients (56 ppm after dilution). The reduced fertilizer treatment consisted of three weekly applications of the same fertilizers at one-eighth of the above concentrations. The standard fungicide treatment consisted of weekly applications of benomyl (Benlate) plus DCNA (Botran) (10 g each/10 liters water). The reduced fungicide treatment consisted of biweekly applications of the same fungicides at a rate of 5 g each/10 liters water. Fertilizer and fungicide applications commenced at seedling age 1 week; fertilizer concentration was doubled after age 10 weeks.

Seedlings were grown for 20 weeks in a polyethylene greenhouse with ambient temperature ranging from 22 to 30 °C, and photoperiod of 18 hours supplemented with high-pressure sodium vapor lights (165 µE/m/s). Seedlings were automatically watered with boom sprayers three times weekly.

Experiment 2. Nine fungal treatments (uninoculated control, *Suillus luteus*, *Pisolithus tinctorius*, *Hebeloma crustuliniforme* (Bull.) Quel., *Laccaria laccata* (Scop.: Fr.) M.C. Cooke, and treatments with autoclaved inoculum of the four fungi) were arranged in a completely randomized design with 16 seedlings per treatment combination and replicate. The autoclaved inocula were included to evaluate any growth regulation by the inoculum substrate (11). The autoclaved inoculum was prepared by placing it in an electric soil sterilizer at 85 °C for 3 hours. One part of inoculum was thoroughly mixed with 10 parts of sterilized growth medium. All seedlings were grown under the reduced fertilizer/reduced fungicide regime described in experiment 1. Experiment 2 was conducted concurrently with experiment 1 under the same environmental conditions.

For both experiments, all seedlings were harvested after 20 weeks, and ectomycorrhizal colonization, shoot height and dry weight, stem caliper, root area index, and dry weight were measured. Ectomycorrhizal colonization was characterized on a subsample of 5 seedlings from each treatment replication, using standard techniques (11). To confirm ectomycorrhizal

Table 2—*Ectomycorrhizal colonization and growth of containerized European larch seedlings inoculated with 5 fungal species and grown under 4 regimes of fertilization and fungicide application (experiment 1)*

Fertilizer treatment	Fungicide treatment	Fungus treatment	Ectomycorrhizal short roots (%)	Height (cm)	Stem diameter (mm)	Shoot dry weight (g)	Root dry weight (g)	Shoot–root ratio	Root area index (cm²)
Standard	Standard	Control	1[a]	29.8	3.5	1.66	0.44	3.7	28.9
		Cenococcum geophilum	7	29.5	3.4	1.56	0.44	3.6	32.6*
		Suillus granulatus	3	28.1	3.3	1.46	0.37*	4.0	29.0
		Suilllus grevillei	3	30.0	3.3	1.57	0.40	3.9	28.6
		Suillus luteus	2	29.6	3.4	1.68	0.44	3.8	31.5
		Suillus tomentosus	1	29.1	3.2	1.40	0.37*	3.8	26.8
Standard	Reduced	Control	5	30.5	3.4	1.97	0.43	4.6	32.7
		Cenococcum geophilum	18	28.5	3.3	1.68	0.40	4.2	28.8*
		Suillus granulatus	5	27.9	3.2	1.58	0.39	4.1	28.3*
		Suillus grevillei	7	30.4	3.4	1.91	0.47	4.1	32.3
		Suillus luteus	9	28.2	3.1	1.67	0.45	3.7	30.8
		Suillus tomentosus	5	30.0	3.3	1.84	0.45	4.1	28.3*
Reduced	Standard	Control	5	17.4	2.4	0.73	0.41	1.8	34.5
		Cenococcum geophilum	17	14.6	2.2	0.62	0.40	1.6	33.0
		Suillus granulatus	18	14.8	2.2	0.56	0.30*	1.9	27.3*
		Suillus grevillei	8	18.6	2.5	0.76	0.41	1.9	33.0
		Suillus luteus	13	18.8	2.6	0.84	0.53*	1.6	39.4*
		Suillus tomentosus	15	15.4	2.3	0.65	0.33*	2.0	27.8*
Reduced	Reduced	Control	8	17.2	2.4	0.76	0.33	2.3	26.0
		Cenococcum geophilum	7	19.3	2.6	0.81	0.38	2.1	30.1*
		Suillus granulatus	16	17.5	2.3	0.65	0.31	2.1	27.2
		Suillus grevillei	9	17.0	2.3	0.66	0.38	1.7*	31.8*
		Suillus luteus	9	15.6	2.2	0.66	0.33	2.0	27.5
		Suillus tomentosus	7	16.7	2.2	0.66	0.30	2.2	25.2

*Significantly different ($P \leq 0.05$) from respective control.

[a] *Thelephora terrestris* ectomycorrhizae developed on control seedlings following contamination.

development, sample root segments were sectioned and stained to confirm presence or absence of Hartig net (1). Seedling root area index (a two-dimensional estimate of root system size) was measured with a LI-COR LI-3000 portable area meter. All data were subjected to analysis of variance, and differences among means were compared by the least significant difference test ($P < 0.05$).

Results

Experiment 1. Root systems of control seedlings were infected with *Thelephora terrestris*. Ectomycorrhizae formed by each of the test isolates did not differ significantly from the control (table 2). Ectomycorrhizal colonization was significantly lower on seedlings supplemented with standard fertilizer treatments compared to reduced fertilizer. The two rates of fungicide application had no significant effect on ectomycorrhizae. Ectomycorrhizal infection, even at these low rates, reduced seedling growth, but only root dry weight, shoot-root ratio, and root area index were significantly affected.

Fertilizer treatment significantly influenced seedling growth. Seedlings supplemented with standard fertilizer were nearly twice the size of those receiving the reduced fertilizer rate. However, root dry weight and root area index were unaffected by fertilizer, presumably because of the restricted root volume of the containers, resulting in a shoot-root ratio of about 2.0 for the reduced-fertilizer treatment compared to about 4.0 for the highly fertilized seedlings. Fungicide application rate did not significantly affect seedling growth.

Experiment 2. Ectomycorrhizal infection by *Hebeloma crustuliniforme* (63%) and *Laccaria laccata* (24%) was significantly greater than infection by *Thelephora* ectomycorrhizae on control seedlings (table 3). Ectomycorrhizal colonization generally decreased seedling size as in experiment 1. The *Hebeloma* and *Laccaria* isolates significantly reduced shoot growth, but only *L. laccata* reduced root growth. Consequently, the shoot-root ratio of *H. crustuliniforme*—infected seedlings was significantly lower than that of the control.

Discussion

The ectomycorrhizal colonization of container-grown European larch in experiment 1 was relatively low compared to other tests with larch seedlings (2, 13). Previously, Molina (13) reported

Table 3—*Ectomycorrhizal colonization and growth of containerized European larch seedlings inoculated with viable and autoclaved cultures of 4 fungal species and grown under a reduced fertilization and fungicide regime (experiment 2)*

Fungus treatment	Ectomycorrhizal short roots (%)	Height (cm)	Stem diameter (mm)	Shoot dry weight (g)	Root dry weight (g)	Shoot–root ratio	Root area index (cm^2)
Control	1	18.5	2.3	0.67	0.30	2.2	26.5
Suillus luteus	4	15.3*	2.2	0.61	0.28	2.2	23.1*
Pisolithus tinctorius	5	15.1*	2.2	0.57*	0.27	2.1	25.1
Hebeloma crustuliniforme	63*	14.0*	2.0*	0.50*	0.29	1.7*	25.7
Laccaria laccata	24*	16.0*	2.1*	0.57*	0.26*	2.2	19.9*
Suillus luteus (dead)	1	15.9*	2.2	0.63	0.30	2.1	24.9
Pisolithus tinctorius (dead)	1	16.0*	2.2	0.58*	0.26*	2.2	23.9
Hebeloma crustuliniforme (dead)	1	15.9*	2.1*	0.53*	0.23*	2.3	22.0*
Laccaria laccata (dead)	1	16.9	2.3	0.70	0.28	2.5	22.9*

*Significantly different ($P \leq 0.05$) from the control.

that *Laccaria laccata* and *Cenococcum geophilum* Fr. formed abundant ectomycorrhizae on western larch (*Larix occidentalis* Nutt). In our experiment 2, ectomycorrhizal colonization by *Laccaria laccata* and *Hebeloma crustuliniforme was* more abundant compared to the uninoculated seedlings, under the prevailing environmental conditions. Growth media inoculum density was greater in experiment 2 than in experiment 1. Thus, fungal propagule density and/or viability was probably adequate for the *Laccaria* and *Hebeloma* isolates. The poor colonization of European larch by *Suillus* and *Cenococcum* isolates may be a result of inoculum with low viability (13), incompatible host-fungus combinations (7, 18), or greenhouse cultural conditions that inhabited ectomycorrhizal symbiosis (11).

Autoclaving inoculum of all four species resulted in significant decreases of some seedling growth variables compared to the uninoculated control (table 3). This occurrence is not unusual because autoclaving inoculum and vermiculite may release fungal toxins, toxic levels of manganese, or other breakdown products (personal communication, J.G. lyer, University of Wisconsin—Madison).

The reduced application of the fungicides benomyl and DCNA in this study, even at low concentrations, did not significantly suppress ectomycorrhizal development of European larch. Applications of captan, zineb, thiram, benomyl, and chlorothalonil have reportedly both increased and decreased ectomycorrhizal development of conifers under various cultural conditions (5, 9, 15, 17). The effect of fungicides seems to be specific to individual tree and fungal species. Due to the widescale problem with *Botrytis* infection of European larch, it would be difficult to produce healthy seedlings without frequent use of fungicides (4).

Ectomycorrhizal colonization of container-grown seedlings under routine greenhouse conditions rarely increases seedling growth (12, 14). Seedling size was reduced in our study even at low rates of ectomycorrhizal colonization. The fungal symbiont may utilize up to 20% of the host photosynthate, thereby reducing seedling size (12). The reduction in fertilizer applications in this study stimulated ectomycorrhizal development by some fungal isolates, but seedling size was not improved. Molina and Chamard (14) and Langlois and Fortin (6) concluded that large ectomycorrhizal conifer seedlings could be obtained by carefully selecting fungal isolates and precisely adjusting fertilizer applications.

Cultural regimes currently used for producing container-grown European larch seedlings are apparently not suitable for ectomycorrhizal colonization by most fungi tested in this study. The higher-fertility regimes and restricted rooting volume of the containers in this study produced excessive shoot growth with no proportional increase in root mass or ectomycorrhizal colonization. Wenny and Dumroese (19) recently reported a successful production regime for container-grown western larch whereby macronutrient fertilization is stopped after week 9. This low-fertility regime may also improve ectomycorrhizal development of larch seedlings (10). Fertilization and pesticide application regimes for producing container-grown European larch should be modified to encourage ectomycorrhizal development of seedlings (2). Moreover, further tests are needed to identify additional isolates of ectomycorrhizal fungi that are compatible with European larch.

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Intermediate Transplanting of Black Spruce Mini-plug Seedlings into Paperpots

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Black spruce (Picea mariana *(Mill.) B.S.P.) were grown in Castle and Cooke Mini-plugs and transplanted at 8 weeks into FH508 paperpots. Mean dry weight of transplanted Mini-plug seedlings was nearly three times that of their nontransplanted counterparts after 14 weeks. However, mean dry weight was only 45% of that of seedlings grown continuously in FH508 paperpots, and size and weight were closer to those of seedlings grown in FH308 paperpots.* Tree Planters' Notes 40(2):18-21; 1989.

Greenhouse space limitations and unit production costs often become a major source of concern for growers whenever larger containers are needed to grow larger seedlings. Although we know that seedling morphology is strongly influenced by plant spacing and rooting volume, a compromise is frequently struck that leads to selection of a container that is still too small, especially in diameter, for the revised crop specifications.

Although the idea is not new, an attractive alternative approach to growing larger stock is to start seedlings in small containers ("mini-plugs"), and to transplant them into the optimum final container at some later date. In northern climates, costs incurred in the production of 1-year-old or older spruce container stock are highest in early spring when crops are being germinated and grown in heated greenhouses. In comparison with conventional practice, a growing regime based on intermediate transplanting would allow high seedling densities during this period of highest greenhouse operating costs. This would thereby reduce the requirement for heated greenhouse space and perhaps lower the unit cost of the final shipped product. As an added economic benefit, intermediate transplanting has the potential for ensuring full stocking within trays of containers during the remainder of the growing period.

This note describes a preliminary trial to test the use of miniplugs for transplanting black spruce (*Picea mariana* (Mill.) B.S.P.) seedlings into Japanese paperpots. The commercially produced mini-plug was developed in California for use in the vegetable and bedding plant industries (Castle and Cooke Transplant Techniculture, Inc., Salinas, CA). The plug consists of a peat moss substrate stabilized with a nontoxic, rubber-like binder, which produces a cohesive yet porous plug with a preformed sowing cavity. This high-density system is well suited to mass greenhouse culture and automated intermediate transplanting.

Methods

In this greenhouse experiment, the growth of seedlings raised in Castle and Cooke CC-09 Mini-plugs (1 .3 cm diameter by 4.4 cm deep; 3834 cavities/M^2) and later transplanted into FH508 Japanese paperpots was compared with that of control seedlings grown from the beginning in FH508, FH408, and FH308 paperpots (respectively, 5.0 x 7.5 cm with 616 cavities/m2, 3.8 x 7.5 cm with 1066 cavities/m^2, and 3.0 x 7.5 cm with 1709 cavities/m^2).

Trays of paperpots (all three sizes) were filled with a 2:1 peat moss—vermiculite mixture; they were then sown with two seeds per paperpot cavity and covered with a thin layer of #10 silica grit. The Castle and Cooke Mini-plug trays were already filled with moist, cured growing medium (hereafter referred to as CC-09 plugs) when received from the manufacturer. Two seeds were sown per plug, and care was taken to place the seeds at the bottom of the sowing cavity. No seed cover was used. Sowing was completed on 8 February, and treatment trays were arranged in a randomized block design with four replications. The experimental unit was a single tray of containers or plugs (FH508 = 200 cavities, FH408 = 336 cavities, FH308 = 532 cavities, CC-09 = 400 cavities).

Germination in both paperpots and mini-plugs was completed in approximately 10 days. Seedlings were thinned to one per cavity on 28 February (20 days). As soon as the seedlings had reached the stage of primary needle initiation (11 days after germination), all treatments were placed on a constant fertilization program. A balanced water-soluble fertilizer (Plant Prod® 20-20-20) that contains micronutrients was used. Nutrients were applied initially at the rate of 50 ppm N; then the rate was increased to 100 ppm N after 2 weeks. Greenhouse temperatures ranged from 22 °C to 27 °C (72 °F to 81 °F), and daylength was extended to 18 hours with 1,000-watt G.E. Multi-Vapor H.I.D. lamps.

Eight weeks after germination, CC-09 plug seedlings were carefully dibbled into additional trays of FH508 paperpots filled with the same peat-vermiculite mixture used for the controls. After a thin layer of silica grit was applied, the trays of transplanted seedlings received an initial application of 300 ppm N of the same fertilizer to boost nutrient levels in the fresh peat; they were then re-randomized within the experiment. The experimental design included trays of non-transplanted CC-09 plugs. Subsequent tending and nutrition were the same for all treatments.

Seedling measurements began 2 weeks after germination and were repeated at 2-week intervals until the experiment was terminated at 14 weeks. Ten randomly selected seedlings per replicate were taken at each sampling date. Data were analyzed by two-way ANOVA for each sampling date; treatment means were separated by Tukey's multiple comparison test.

Results and Discussion

Growth progressions for shoot height and total seedling dry weight are illustrated in figure 1. In paperpots, each size of container produced a distinctly different growth curve. Although differences in shoot height were not significant (P = 0.05) on any sampling date, differences in total dry weight were highly significant (P = 0.01) at 12 and 14 weeks. The final mean dry weight of FH508 seedlings was 51 and 108% greater, respectively, than that of FH408 and FH308 seedlings. Final height-diameter ratios were also affected significantly, with the highest values in FH308 (11.8), followed by FH408 (10.0), and FH508 (8.9) seedlings. As a result of their closer spacing, FH308 paperpots produced seedlings with fewer side shoots and sparser foliage than did paperpots of other sizes (fig. 2).

In the CC-09 plugs, spacing and substrate volume restricted seedling growth from a very early age, and only small, slender seedlings resulted (fig. 2). The most dramatic effect was upon seedling dry weight (fig. 1). Although not evident visually, significant differences in dry weight were present as early as the first sampling date (2 weeks after germination), when seedlings had barely completed primary needle initiation. By the fourth week, CC-09 seedlings were only half the dry weight of FH308 seedlings; by 14 weeks, nontransplanted plug seedlings had only one-third the dry weight of FH308 seedlings.

Although the small size of the CC-09 plug was undoubtedly the principal restriction upon seedling growth, other factors may have contributed to the early stagnation observed. In comparison with the peat-vermiculite mixture used in the paperpots, Mini-plugs did not drain well after watering. Especially during the first 6 to 8 weeks, when seedlings were small and unable to take up the excess moisture, the plugs often remained saturated for extended periods after watering. This suggests that the oxygen supply to roots may have been inadequate at times, and may account for the significant depression in very early seedling dry weights. Later, plugs were also prone to excess salt accumulation. Because they did not drain well, it was difficult both to maintain a continuous flushing action through the substrate during normal fertilization, and to leach the substrate when soluble salt levels reached a critical level. Although there was no direct evidence to link these factors with the observed results, it remains possible that, by adversely affecting root health

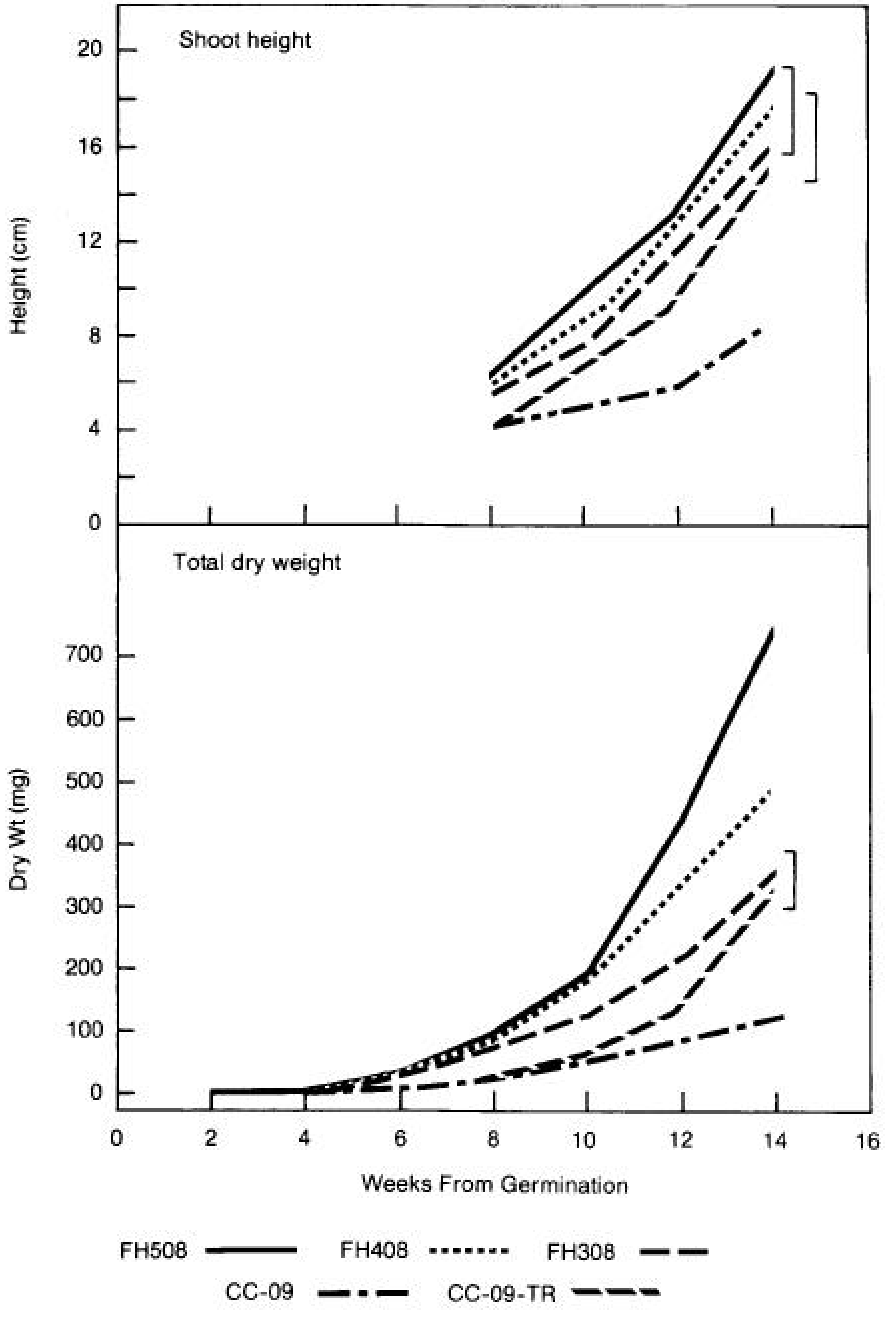

Figure 1—*Growth progressions for shoot height and total seedling dry weight. Bracketed means are not significantly different (P = 0.05) at 14 weeks (Tukey's multiple comparison test). (N = 40)*

and vigor, they might have weakened the ability of CC-09 plug seedlings to grow optimally after transplanting.

As it was, CC-09 plug seedlings responded quickly when transplanted into FH508 paperpots. Improvements in seedling color and increased shoot growth became evident within 1 week after transplanting. However, although shoot height increased rapidly, dry matter accumulation continued to lag until week 12 (fig. 1). Thereafter, transplanted seedlings (CC-09-T) grew rapidly and, by the time the experiment was terminated at 14 weeks, they had a mean dry weight nearly three times that of their nontransplanted counterparts. This resulted in seedlings not significantly different in size and weight from those grown in FH308 paperpots, although transplanted seedlings exhibited substantially better shoot form with more numerous side shoots (fig. 2). Nevertheless, transplanted seedlings were still 32 and 55% lighter, respectively, than seedlings grown continuously in FH408 and FH508 paperpots.

Because of the preliminary nature of this experiment, it was not continued beyond the greenhouse phase even though, in an operational setting, seedlings would normally be grown on outdoors to the end of the first or into the second growing season. The experiment showed that mini-plug seedlings can

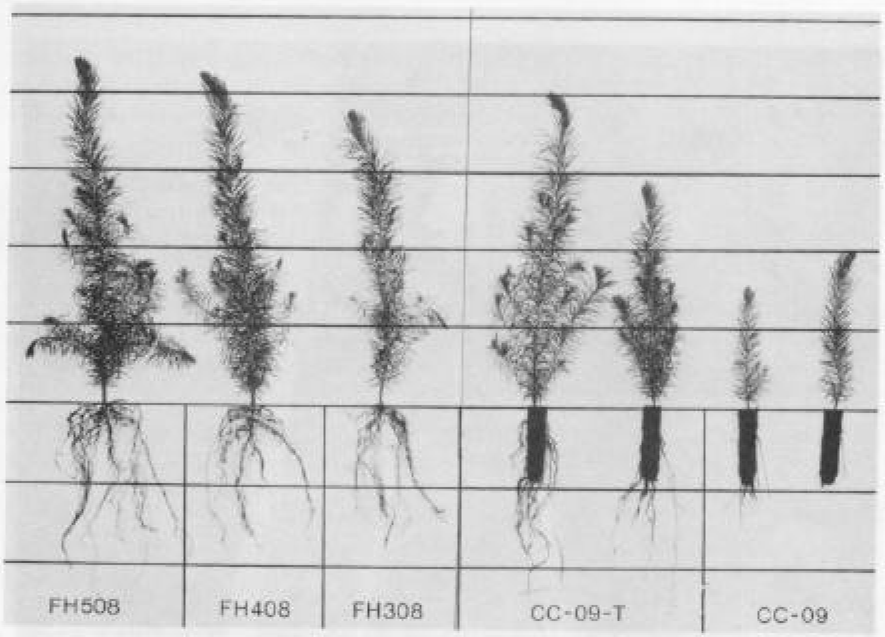

Figure 2—*Fourteen-week-old black spruce seedlings grown in three sizes of paperpot (FH508, FH408, FH308), as Mini-plug transplants into FH508 paperpots (CC–09–T), and continuously grown in Castle and Cooke Mini-plugs (CC–09). Horizontal line spacing is 5 cm.*

respond quickly after transplanting into larger containers, but perhaps not without penalty in comparison with conventionally grown container stock. The data indicate that intermediate transplanting produced seedlings with only 45% of the biomass of those grown from the beginning in the same size of final container (FH508). Although the gap might have been reduced if seedlings had been allowed to grow on outdoors, we have to question the acceptability of such a large reduction in growth potential.

It is possible that the cultural problems experienced with miniplugs, by causing an early check to seedling growth, may have exaggerated the difference between transplanted and nontransplanted seedlings. It is also possible that the transplanting date was inappropriate. Observations of seedling form and rooting habit suggested that black spruce seedlings should not be held in CC-09 plugs longer than about 8 weeks after germination before they are transplanted. Were these seedlings held too long? Would there have been less of a lag in dry matter accumulation if seedlings had been transplanted earlier? These are some of the biological questions that need to be addressed if mini-plugs are to be an acceptable vehicle for intermediate transplanting.

Comparison of Planting Tools for Containerized Seedlings: Two-Year Results

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Three planting tools—a planting tube, a bar, and a dibble—were evaluated for planting errors with containerized seedlings. Bar planting resulted in a significantly greater percentage of seedlings being planted too shallow than did planting with either of the other two tools, whereas the planting tube had a significantly greater percentage of trees planted too deep. There were also significant differences between the tools in percentage of packing errors. None of the planting errors were severe enough to affect survival after 2 years, but high mortality due to drought may have masked planting error effects. Survival differences were found between the planting sites because of drought, but were unrelated to type of planting tool. Tree Planters' Notes 40(2):22-24; 1989.

Containerized tree seedlings have been used in Minnesota since 1967. Ontario tubelins—$^{9}/_{16}$—3-inch tubes—were first used, and planting was done mostly with a blunt-tipped dibble or rod. Several years later, when paperpots, bookplanters, and Styroplugs were introduced, the primary tool was the Finnish Potiputki, from which a number of other planting tool innovations were developed. These were designed to increase planting speed, minimize planters' fatigue by allowing planting from an

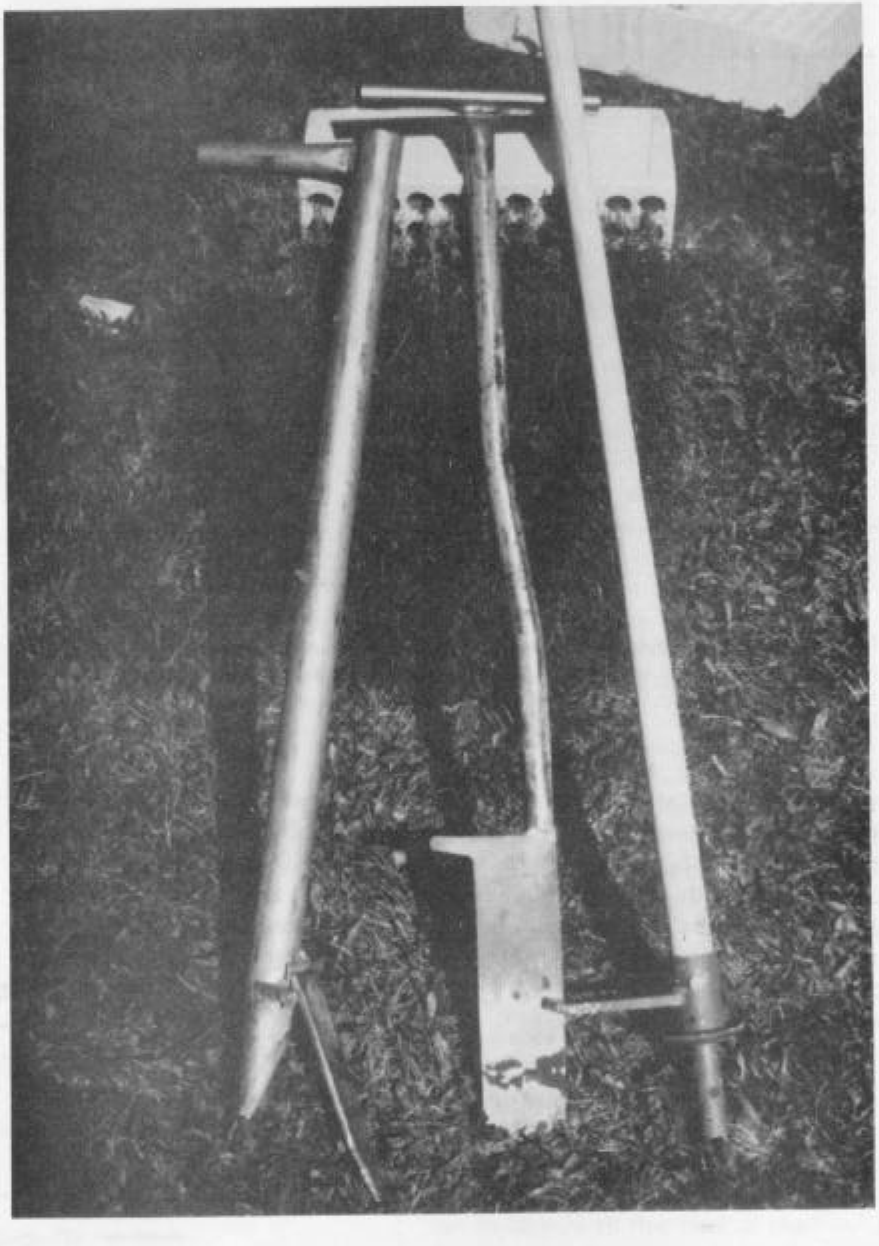

Figure 1—*The three planting tools used in the study* **(left to right):** *planting tube, bar, dibble.*

upright position, and improve the quality of tree planting.

In 1984, the St. Louis County (Minnesota) Department of Land Investment began using containerized seedlings for reforestation. A tube-type tool designed by Moorhead Manufacturing was used to plant nearly a half-million Styro-4A seedlings in 1985. During 1986, it was noted that seedlings planted with this tool were often too shallow and loosely packed. This problem was partly attributed to the larger diameter of the planting tube (1¾ inches) in relation to that of the Styro-4A seedling (about 1 inch). Because of these problems, an operational trial was set up to evaluate the original tool and several others. This paper summarizes results of planting error determination and first-year and second-year survival. A follow-up survey, including height growth, will be made after four growing seasons.

Materials and Methods

Three tools were evaluated: a round **dibble**-type bar, 5¼ inches long and 1 inch in diameter, with a blunt end; a flat **bar**, 10 inches long, such as is normally used for bareroot stock; and the original planting **tube** used in 1985 and 1986 (fig. 1). Three planting sites were selected with various soil textures: (1) gravelly, very fine sandy loam; (2) sandy loam; and (3) coarse sandy loam. At each site, four rows were randomly selected to serve as blocks. Each tool was then used to plant 25 seedlings in each row. The same personnel who normally carry out planting operations were used for these experiments. The seedlings were classified after planting for planting depth and packing around the seedling. The following classifications were used.

Planting depth:

Correct = root collar at mineral soil surface.

Shallow =root collar ½ inch or more above mineral soil surface.

Deep = root collar more than ½ inch below soil surface.

Seedling packing:

Good =root system remains firmly packed after a tub on the seedling's foliage.

Fair = root system is partially dislodged by a tug on the seedling's foliage.

Poor = seedling is lifted from planting hole by test tug.

Survival was determined after the first and second growing seasons. Arc sine transformation and two-way analysis of variance were used to analyze the data.

Results

Soil type did not significantly affect the percentage of planting errors in this study, so data were pooled over sites during analysis of the study results.

The percentage of seedlings planted too shallow was 5% higher with the planting bar than with either the dibble or the planting tube. However, this is probably no greater than the amount of variation that might occur with any planting tool. The percentage of seedlings planted too deep was from 10 to 12% higher with the planting tube than with either of the other two tools. This is a substantial difference and is seemingly related to the design of the tool. This is probably a result of the larger than needed hole made by the planting tube, both in depth and diameter (table 1).

The percentage of seedlings classified as well packed was significantly lower with the planting dibble than with the bar but neither varied from the planting tube in this category. The poorest packing was with the planting tube and planting dibble, but these did not significantly vary from the planting bar. Again the variation between the three tools was of little consequence regarding poor packing (table 2).

Table 1—*Percentage of planting depth errors by tool*

Planting tool	Percent of errors		
	Correct depth	Too shallow	Too deep
Dibble	68 a	2 a	30 a
Bar	66 a	7 b	27 a
Tube	58 a	2 a	40 b

Means within a column followed by the same letter do not differ significantly at the 0.10 level.

Table 2—*Percentage of packing errors by tools*

Planting tool	Percent of errors		
	Good packing	Fair packing	Poor packing
Dibble	69 a	26 a	5 a
Bar	85 b	14 b	1 a
Tube	78 ab	18 ab	4 a

Means within a column followed by the same letter do not differ significantly at the 0.10 level.

Table 3—*Percentage survival by tool type and site*

Planting tool	Site	Percent Survival	
		First-season survival	Second-season survival
Dibble	1	95 b	36 b
	2	99 a	74 a
	3	100 a	68.5 a
Bar	1	93 b	45 b
	2	98 a	83.8 a
	3	99 a	73 a
Tube	1	95 b	40 b
	2	100 a	81 a
	3	100 a	71.8 a

Means within a column followed by the same letter do not differ significantly at the 0.10 level.

The type of planting tool did not significantly affect survival after two growing seasons (table 3). There was no relationship between either planting depth or degree of packing and survival. However, any effect of these factors was likely masked by a drought during the second growing season, which greatly reduced seedling survival. Precipitation was 8.4 inches below normal for that growing season, and seedling survival was affected on all three sites. Site 1 (gravelly, very fine sandy loam soil) was significantly lower than either site 2 or 3.

These results are not necessarily revealing regarding impact of planting tool selection and planting errors relating to seedling survival. However, with the current high cost of artificial regeneration, namely tree planting, it is imperative that we reduce planting errors and use the tool most suitable for the assigned task. We should strive to maintain high standards on those aspects of regeneration that we can control, such as planting stock quality and proper seedling placement.

Catkin Growth, Seed Production, and Development of Seed Germinability in Quaking Aspen in Central Alberta

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*Initial release of seeds of quaking aspen (*Populus tremuloides *Michx.) differed by 2.5 weeks between 1984 and 1988 but began in both years when catkin moisture content was less than 70%. Germinability of freshly extracted seed increased as the collection date approached the time of release. Artificial ripening increased germination speed of seed collected 8 days before a release.* Tree Planters' Notes 40(20):25-29; 1989.

Populus tremuloides Michx., quaking aspen, is a widespread tree of northern and western North America and has become important as a source of fiber (1). *P. tremuloides* may be readily propagated from adventitious shoots (suckers) arising from large lateral roots (7) or via tissue culture (9), but propagation by seed may be a desired alternative for purposes of research or reforestation (3, 8).

Production of abundant seed crops in aspen may occur only at 3- to 5-year intervals (8). The seed mature and are released within a few weeks after fertilization (6). The seed become difficult to collect in quantity upon release and the viability of released seed declines rapidly under field conditions (8). Thus, proper timing of seed collection is important to maximize efficiency of seed collection and to ensure maximum viability of collected and stored seed.

It is unclear from the literature when maximum germinative capacity is reached relative to catkin development and seed release; it is also unclear how the timing of these events varies from year to year in a given area. The purposes of this study were to

1. Relate catkin moisture content and dry mass to germinative capacity of seed and timing of seed release during 2 years (1984 and 1988) of abundant seed production.
2. Describe gross qualitative characteristics of seed as related to seed germinability.
3. Estimate seed production per capsule and catkin as an aid to increasing efficiency of seed collection.

Methods

Pistillate catkins were collected from 3 to 5 aspen trees growing along the upper bank of the North Saskatchewan River in Edmonton, AB (53° 34' N, 113° 31', W; elev. 671 m). The trees were separated by distances of 50 m or more and were assumed to have been from separate clones. Catkins were collected from different trees in 1988 than in 1984.

Collections began when catkins were clearly visible, within a month of seed release. In 1984, catkins were collected on four dates during a 23-day period before seed release; in 1988, catkins were collected on six dates over a 16-day period.

Collected catkins were divided into subsamples for determinations of fresh and dry mass, moisture content, and germinability of freshly extracted seed. Dry mass and moisture contents were determined on 4 to 6 catkins after fresh mass measurements and ovendrying at 70 °C for 24 hours. Seed were extracted from individual flowers in a second subsample of catkins from each tree, teased free of attached fluff, and placed on moistened filter paper in petri dishes.

Seed collected in 1988 were allowed to germinate for up to 7 days under constant light and at 22 °C; seed collected in 1984 were allowed to germinate under the same conditions, but for shorter periods. The number of seed sampled per tree ranged from 25 in early collections to 65 in later collections. Although the duration of the test was shorter than recommended for aspen seed (8), normally developing seed germinates readily within 1 to 3 days at germination temperatures greater than 15 °C (10).

The 7-day germination test should therefore clearly indicate differences in seed maturation and germinability. The numbers of germinated seed (defined as those with cotyledons lifted off the filter paper and with visible root elongation) were counted daily. Seed production per capsule and per catkin were also determined on this subsample of catkins.

A second sample of caktins, collected 11 and 7 days before release, was air-dried for 3 or 6 days. Seed were than extracted and germinated under the same conditions as were the freshly extracted seed. Additionally, seed produced per capsule and catkin were counted on catkins from 3 trees just before seed release in 1988.

Changes in catkin moisture contents, rates of dry matter accumulation (normalized as a proportion of final catkin dry mass), and timing of seed release were compared with climatic data collected at the Edmonton Municipal Airport (2). Maximum daily vapor pressure deficit (VPD) was calculated from recorded daily maximum temperatures and minimum daily relative humidities to indicate the "drying power" of the atmosphere on a given day.

Results

Seed release began 2.5 weeks earlier in 1988 than in 1984 (fig. 1). Catkin growth rates appeared to be greatest from 23 to 14 days before seed release in 1984 and from 11 to 7 days before seed release in 1988. The peak periods of catkin growth in each year may have been related to mean daily growing degree days (GDD) in the previous sampling period (table 1), although data were limited.

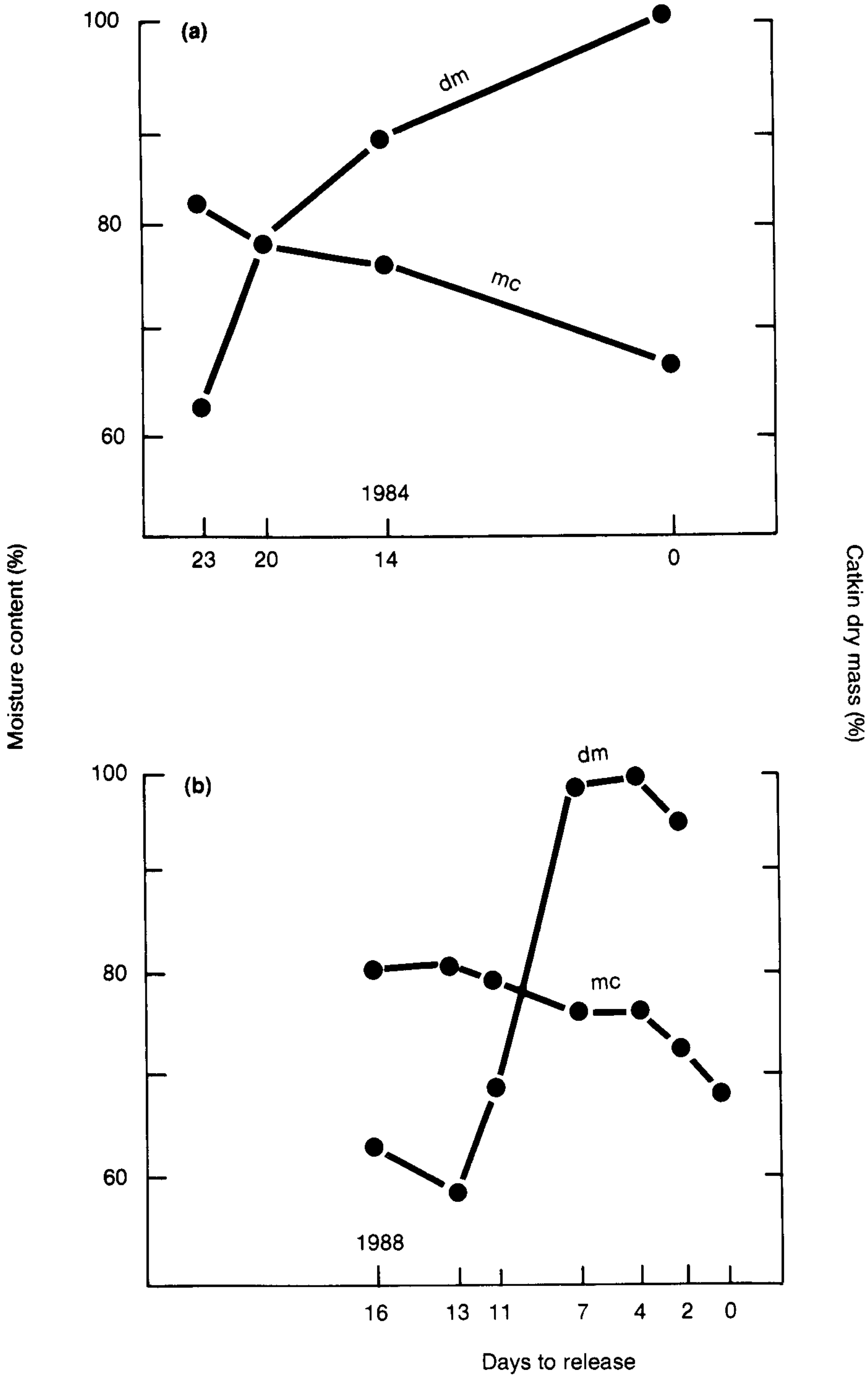

Figure 1—*Change in mean catkin dry mass and mean moisture content over time in 1984* **(A)** *and 1988* **(B)**. *Day 0 represents the day seed release began in each year (May 24 in 1984, May 9 in 1988). MC = moisture content (% of fresh mass), dm = percent of final catkin dry mass.*

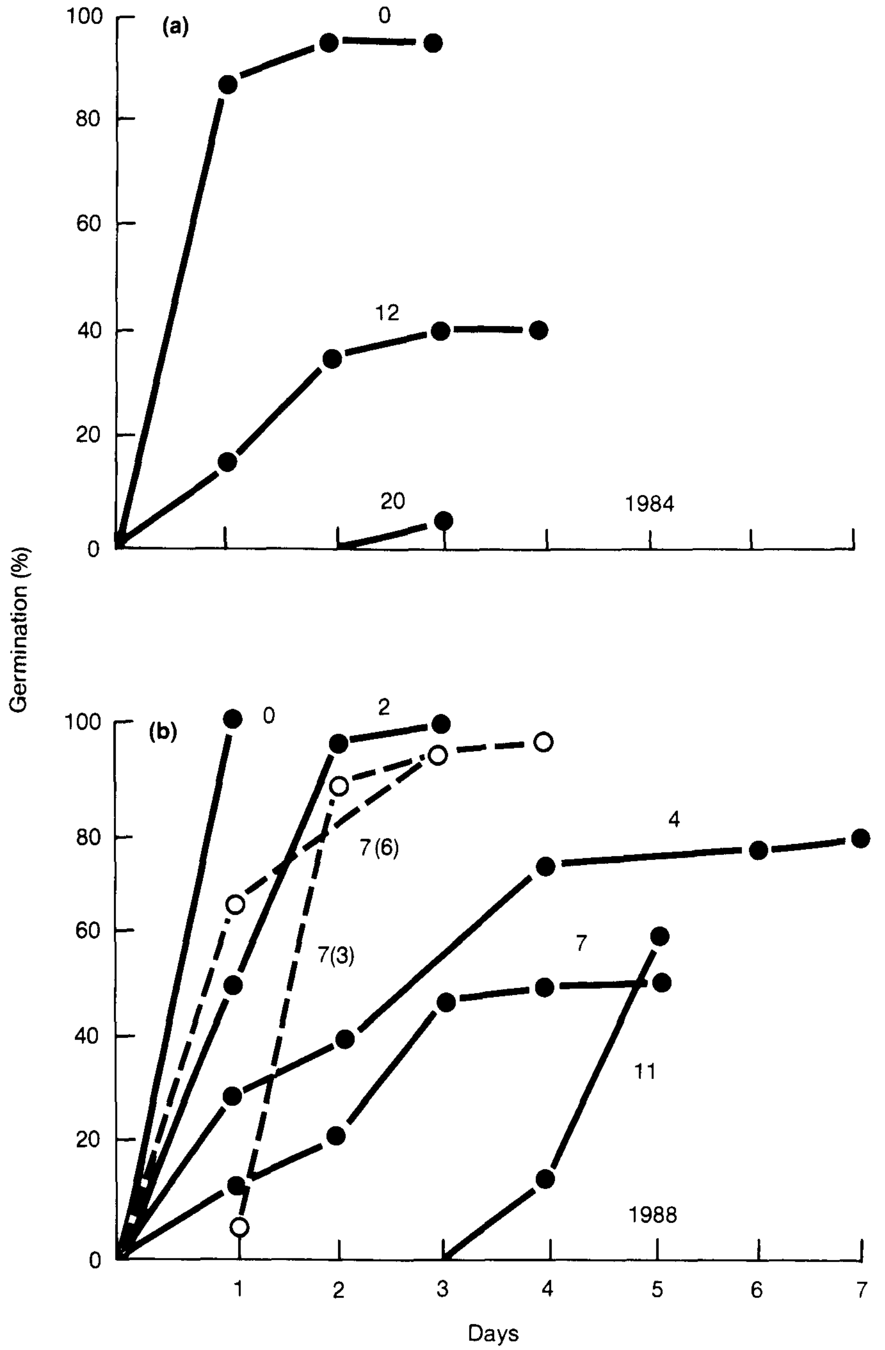

Figure 2—*Percentage germination over time as a function of collection date for 1984* (**A**) *and 1988* (**B**). *The number adjacent to each line indicates the number of days before seed release that seed was collected; the artificial ripening period, if any, is shown in parentheses.*

In both years, catkin moisture contents decreased from about 80% at the first collection to less than 70% at the time seed was released (fig. 1). In 1988, decreased moisture contents from 16 to 7 days before release were due to increases in catkin dry mass; subsequent decreases were due to water loss from the catkins. Rates of moisture loss nearer the time of release (14 to 0 days in 1984 and 7 to 0 days in 1988) were related to vapor pressure deficits (table 1).

The date of collection and extraction had significant effects on germination of freshly extracted seed after 2 and 4 days (table 2). Germination speed (indicated by the time required for 50% germination) increased with each successive collection date (fig. 2a). No seed collected 13 or 16 days before seed release in 1988 germinated.

Air-drying of catkins collected 7 days before seed release in 1988 enhanced both germination speed and percentage relative to that of seed collected at the same time, but extracted and tested immediately (fig. 2b). The ripening procedure had no effect, however, on seed collected 11 days before seed release (data not shown).

The seed contained in catkins collected early in the 1984 and 1988 sampling periods were a pale whitish-green and the cotton was moist, making extraction of seed difficult. Within 14 days of seed release in 1984 and at 4 days before seed release in 1988, seed were straw or tan colored. Cotton appeared much drier at the time of seed extraction and expanded rapidly when capsules were artificially opened; seed were readily teased free of the cotton.

The mean number of capsules per catkin, but not seed number per flower, varied considerably among the trees sampled in 1988 (table 3). Seed production of individual catkins ranged from 98 seed (tree 4) to 831 seed (tree 2); mean production was 450 seed per catkin. Seed production per catkin was estimated from catkin fresh mass by the relation

[1] $S = 381.7\ FM + 184$

$(r = 0.76, n = 19, P = 0.001)$

where S = seed number and FM = catkin fresh mass (in grams).

Discussion

Dates of initial flowering and seed release of aspen in the Edmonton area may vary by as much as 5 and 3 weeks, respectively (4, 5). Seed release began in 1984 at a time typical of reported values for the area (4). The earlier release of seed in 1988 may have been releated to weather conditions, which were warmer and drier than normal (2). It must be reiterated that catkins were collected from the south sides of a small number of trees in a localized area. My data, while comparable for 1984

Table 1—*Change in catkin dry mass (DMI) and moisture content per day (MCI), and mean daily vapor pressure deficit (VPD) and growing-degree days (GDD) by sampling interval for the 1984 and 1988 collection periods (DMI is normalized such that maximum dry mass for a given tree = 100; GDD is calculated relative to a 5 °C base daily mean temperature*

Days*	DMI(%/day)	MCI (%/day)	VPD (kbar)	GDD
1984				
26–23	—	—	—	3.7
23–20	5.5	−0.013	0.77	2.6
20–14	1.7	−0.003	0.85	2.2
14–0	0.9	−0.007	0.96	5.2
1988				
20–17	—	—	—	1.9
17–11	0.7	−0.007	1.50	8.4
11–7	7.5	−0.008	1.54	5.3
7–4	0.3	0.000	1.16	3.0
4–2	−2.5	−0.015	1.35	6.2
2–0	—	−0.025	2.00	10.6

Correlations

DMI and GDD†				MCI and VPD			
Year	Days	r	n	Year	Days	r	n‡
1984	23–0	0.99	3	1984	20–0	0.85	6
1988	20–4	0.83	4	1988	11–0	—	—
1984	23–0	0.76	7‡				
1988	20–4	—					

*Days prior to initiation of seed release.

†Mean daily growing-degree days (base 5 °C) during previous sampling period.

‡Data from 1984 and 1988 pooled.

Table 2—*Analysis of variance for percentage of germination (arc sine-transformed) after 2 and 4 days as affected by collection/extraction dates of seed in 1988 (DF = degrees of freedom)*

Source	DF	Mean square	F	
2 day				
Total				
Date	4	40.29.8	10.1	P≤0.001
Error	12	397.2	—	
4 day				
Total				
Date	4	2705.7	15.7	P≤0.001
Error	12	172.0	—	

Table 3—*Catkin fresh mass (FMASS), seed production by capsule (S/CP), and capsule production per catkin (CA/CT) for seed collected in 1988*

Tree	FMASS (g)		S/CP		CA/CT	
	Mean ± SE	N	Mean ± SE	N	Mean ± SE	N
2	1.01 ± .06	5	6.9 ± 0.7	24	98.0 ± 6.9	5
3	0.56 ± .03	5	6.4 ± 0.6	24	77.2 ± 2.6	5
4	0.55 ± .23	3	6.5 ± 0.5	21	48.2 ± 9.5	6
5	1.07 ± .03	6	6.6 ± 0.6	10	76.3 ± 3.4	6

and 1988, may not be directly comparable with earlier data (4).

Careful timing of seed collection is required to ensure maximum germinability of collected aspen seed, at least in this portion of its range. Seed collected several days before release may be artificially ripened. These data indicate that, before extensive collection of catkins, visual inspection of catkins and cotton and seed within capsules, combined with moisture content measurements on catkins, may be useful in ensuring maximum germinability of collected seed.

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Fungicides for Control of Sirococcus Tip Blight of Pine at a Northern California Nursery

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Fungicides that could be used as an alternative to chlorothalonil for control of sirococcus tip blight of Jeffrey pine (Pinus jeffreyi *Grev. & Balf.) were evaluated in field trials. Three triazole fungicides (propiconazole, penconazole, and triadimefon) applied at 8-week intervals were as effective as chlorothalonil applied at 4-week intervals.* Tree Planters' Notes 40(2):30-32; 1988

Historically, the fungicide chlorothalonil has been used to control sirococcus tip blight of Jeffrey *(Pinus jeffreyi* Grev. & Balf.) and ponderosa (*P. ponderosa* Laws.) pines, caused by *Sirococcus strobilinus* Preuss, at the Humboldt Nursery (USDA Forest Service) in coastal northern California. In 1981, the nursery terminated the use of the fungicide because chlorothalonil was detected in a tributary stream adjacent to the nursery property. The stream receives overflow from sumps containing drainage and runoff water from production beds during periods of peak rainfall. In 1982, losses in pines due to *S. strobolinus* infection increased dramatically.

Subsequently, a study was initiated to determine the efficacy of fungicides other than chlorothalonil for the control of sirococcus tip blight of Jeffrey and pondersa pines. If any are efficacious, their registration will be pursued with the U.S. Environmental Protection Agency.

Methods

Trial 1 (initial field screening). Fungicide evaluation tests were conducted on a 4-foot-wide by 200-foot-long bed of 1 + 0 Jeffrey pine at the Humboldt Nursery. Five fungicides were evaluated at the recommended label dosages (table 1). The fungicides were mixed with water at the dosages shown and applied to appropriate plots at the rate of 1 gallon per 200 square feet. Fungicides were selected because of past effectiveness against the disease (1) or recently demonstrated systemic activity in controlling other similar diseases.

The experimental design used was alternate treated and untreated plots (4 by 5 feet) with the test fungicides assigned randomly to every other plot, giving a system of paired plots (treated and untreated) in which the treatments were randomly placed. This system was replicated four times down the bed of Jeffrey pine (40 plots total).

Treatment began in September 1982 and continued at approximately 1-month intervals until June 1983. Cankered pine seedlings were counted and removed from each plot monthly. At the termination of the experiment, all remaining seedlings were counted to obtain a total count per plot, and percentage of cankered seedlings was determined. Percentages underwent arc sine transformation for data analysis, and statistical differences between paired plots were determined by a t-test.

Trial 2 (frequency of application). The two most efficacious alternatives to chlorothalonil found in the initial screening—propiconazol and triadimefon—were further tested in 1983-84 to determine the most effective frequency of application. The trial was initiated in November 1983. A randomized complete block design for the following five treatments was used in a 1 + 0 bed of Jeffrey pine.

1. no fungicide.
2. 75% chlorothalonil (2 pounds of Bravo W-75 per 100 gallons) at 4-week intervals.
3. 50% triadimefon (8 ounces of Bayleton 50 WP per 100 gallons) at 4-week intervals.
4. 50% tridimefon (8 ounces of Bayleton 50 WP per 100 gallons) at 8-week intervals.
5. 130 ml of propiconazole (Tilt 3.6 EC) per 100 gallons at 4-week intervals.
6. 130 ml of propiconazole (Tilt 3.6 EC) per 100 gallons at 8-week intervals.

Dr. A. H. McCain, Extension Plant Pathologist, University of California at Berkleley, provided technical advice during initial stages of this study.

Table 1—*Fungicides and application rates evaluated at the Humboldt Nursery, trial 1 (1982–83)*

Common name	Trade name	Rate/100 gal water
chlorothalonil	Bravo W–75	2.0 lb
triadimefon	Bayleton 50 WP	8.0 oz
iprodione	Chipco 26019	1.5 lb
vinclozolin	Ornalin	1.5 lb
etaconazole	Vangard 10W	20 oz

Table 2—*Percentage of Jeffrey pine seedlings infected by* Sirococcus strobilinus *at the Humboldt Nursery, trial 1 (1982–83)*

	Percent seedlings infected	
Fungicide	Treated Plots	Untreated Plots
chlorothalonil	2	47
etaconazole	3	46
triadimefon	5	57
vinclozolin	66	60
iprodione	76	54

Table 3—*Percentage of Jeffrey pine seedlings infected by* Sirococcus strobilinus *at the Humboldt Nursery, trial 2 (1983–84)*

Treatment	Percentage of seedlings infected
propiconazole (Tilt 3.6 EC)	
4-week intervals	2.2 a
8-week intervals	4.4 ab
triadimefon (Bayleton 50 WP)	
4-week intervals	6.3 ab
8-week intervals	9.5 b
chlorothalonil (Bravo W–75)	
4-week intervals	7.9 ab
control	25.1 c

Means followed by the same letter do not differ significantly (P = 0.05) according to Duncan's multiple range test.

Propiconazole, a fungicide of similar chemical structure as etaconazole, was used instead of etaconazole because it was further along in the registration process for the State of California. The experiment was replicated four times. Each replicate covered 18 linear feet of bed (six 3- by 4-foot plots), with the six treatments randomized in each replicate. Efficacy of treatments was evaluated by counting and removing dead or cankered seedlings in July 1984. Remaining seedlings were counted to obtain a total count per plot, and percentage of seedlings infected by *S. strobilinus* in each treatment was determined.

Trial 3 (comparison of triazole fungicides). This trial was begun December 1984. A randomized complete block design for the following three treatments was used in a bed of 1 + 0 Jeffrey pine.

1. no fungicide.
2. 8 ounces of triadimefon (Bayleton 50 WP) per 100 gallons per acre at 8-week intervals.
3. 130 ml of propiconazole (Tilt 3.6 EC) at 8-week intervals.
4. 20 ounces of penconazole (CGA-71817 10W) per 100 gallons at 8-week intervals.

The experiment was replicated five times. Each replicate covered 20 linear feet of bed (five 4-by 5-foot plots), with the four treatments randomized in each replicate. Efficacy of treatments was evaluated by counting and removing dead or cankered seedlings in July 1985. By that time, the experimental bed had been treated three times (February, April, and June). Remaining seedlings were counted to obtain a total count per plot, and percentage of seedlings infected by *S. strobilinus* in each treatment was determined.

Results and Discussion

Although scattered infections appeared in both treated and untreated plots (trial 1) throughout the winter months of 198283, most cankering occurred in April and May, when warmer spring storms arrived. By June 1983 the disease had spread throughout the experimental bed, and differences in infection levels among treatments were obvious. Chlorothalonil, as expected, was most efficacious (table 2). An average of 2% of the seedlings were cankered in plots treated with chlorothalonil, compared to 47% in the adjacent untreated plots.

Etaconazole and triadimefon also effectively controlled the disease. Plots treated with etaconazole and triadimefon had 3 and 5% of the seedlings infected, compared to 46 and 57% infection in adjacent plots. Plots treated with vinclozolin and iprodione had more infected seedlings than adjacent untreated plots; iprodione appeared to increase disease levels.

When chlorothalonil, propiconazole, and triadimefon were compared in trial 2 (1984-85), all five fungicide treatments tested resulted in less than 10% infection and gave significantly better control of sirococcus tip blight than no fungicide treatment (table 3). Although propiconazole at 4- or 8-week intervals and triadimefon at 4- or 8-week intervals were effective, they did not give significantly better protection against the disease than the currently used practice of chlorothalonil at 4-week intervals. However, either of the two fungicides applied at 8-week intervals were as effective as chlorothalonil applied at 4-week intervals. Propiconazole at 4-week intervals gave significantly better control than triadimefon at 8-week intervals.

When a third triazole fungicide, penconazole, was compared directly with prepiconazole and triadimefon in trial 3 (1984-85), all three fungicide treatments were similar in efficacy, resulting in less than 9% infection, and gave significantly better control of sirococcus tip blight than no fungicide treatment (table 4). The penconazole treatment was as effective as the propiconazole treatment.

Table 4—*Percentage of Jeffrey pine seedlings infected by* Sirococcus strobilinus *at the Humboldt Nursery, trial 3 (1984–85)*

Treatment	Percentage of seedlings infected
propiconazole (Tilt 3.6 EC)	
8-week intervals	4.8 a
penconazole (CGA–71818 10W)	
8-week intervals	6.3 a
triadimefon (Bayleton 50 WP)	
8-week intervals	8.4 a
control	21.8 b

Means followed by the same letter are not significantly different (P – 0.05) according to Duncan's multiple range test.

These results suggest that Humboldt Nursery could replace the current treatment of chlorothalonil at 4-week intervals with a treatment of triadimefon, propiconazole, or penconazole at 8-week intervals and obtain the same level of control over sirococcus tip blight. The three triazole fungicides have several advantages over chlorothalonil. They are systemic, ergosterol biosynthesis inhibitors, readily taken up by plants, and would less likely to be washed off by the frequent rains that occur at Humboldt Nursery during the period most favorable to infection. Because they can be applied at half the frequency of chlorothalonil, the amount of pesticides introduced into the nursery environment would be reduced. Propiconazole and penconazole are not yet registered in California as a Section 3 Registration. However, Special Local Need Registration for triadimefon (Bayleton 50 WP) is available. The current label for Bayleton 25 WP lists use for control of *S. strobilinus.*

Alternating fungicides for the control of a specific disease to reduce the risk of resistant fungus strains developing is a standard nursery practice. Humboldt Nursery could alternate triadimefon with the currently used chlorothalonil treatment. For example, if fungicide application for control began in January, triadimefon could be used during this rainy period. Treatment in March (8 weeks later) with chlorothalonil, followed by treatment in April with triadimefon would protect the seedlings over a 6-month period with three fungicide treatments, instead of the six needed if chlorothalonil alone was used.

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Conditioning Three Boreal Conifers by Root Pruning and Wrenching

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The effects of root pruning and wrenching on the morphological quality and outplanting performance of white spruce (Picea glauca *(Moench) Voss) and black spruce* (P. mariana *(Mill.) B.S. P.) and jack pine* (Pines banksiana *Lamb.) seedlings. Root pruning and wrenching successfully modified the morphology of all three species in the nursery by decreasing height and increasing root system size, but did not improve survival or growth after outplanting.* Tree Planters' Notes 40(2):33-39; 1989.

Root pruning and wrenching treatments have resulted in improved seedling morphology and increased survival after outplanting for Monterey pine (*Pines radiata* D. Don.) in New Zealand (6, 18), loblolly pine (*Pines taeda* L.) in the southern United States (19), and Douglas-fir (*Pseudotsuga menzieseii* (Mirb.) Franco) in the Pacific Northwest (22). Root pruning and wrenching modified the morphological quality of red pine (*Pines resinosa* Ait.) in southern Ontario (1-4) and white spruce (*Picea glauca* (Moench) Voss) in northern Ontario (12), but increases in survival and growth after outplanting were only obtained with red pine.

The benefits of root pruning and wrenching in the nursery have been cited as increased root fibrosity, improved shoot-root balance, increased root growth potential, and early cessation of top growth (17, 23). Some nurseries in the Pacific Northwest use root wrenching to prevent late flushing of pines (9). Root pruned and wrenched seedlings may also show better survival through storage, withstand longer periods of root exposure, show increased drought tolerance and have improved growth after outplanting (23).

Problems with the survival and growth of bareroot nursery stock after overwinter storage and outplanting in Ontario resulted in research on root pruning and wrenching white spruce, black spruce (*Picea mariana* (Mill.) B.S.P.) and jack pine (*Pinus banksiana* Lamb.) during the final year on the nursery. A previous study with white spruce (12) indicated that root pruning and wrenching could be used to modify the morphology of white spruce transplants in the nursery but the treatments did not improve survival or growth in the first year after outplanting. The lack of increase in survival or growth after outplanting was attributed to the warm, moist growing season, which resulted in every high survival for all plantations in that year. No trials of root pruning and wrenching black spruce are reported in the literature.

The major problem in producing 2+0 jack pine bareroot stock in northern Ontario is its excessive height growth during the second year on the nursery. This results in tall, unbalanced seedlings. In northern Ontario, jack pine was root pruned early in the spring of the 2+0 year (5). The treatment had no effect on top-root ratio, nor did it increase survival or growth the first season after outplanting. Similar treatments applied to jack pine in the southern United States showed similar results (13). Reports of root pruning combined with wrenching of jack pine are lacking from the literature.

Potassium is thought to increase the cold hardiness of plants, but the literature on this is inconclusive. Some studies have shown increased cold tolerance at high levels of potassium and others no effect. Potassium deficiency has been shown to increase the susceptibility of seedlings to frost damage (15). Increased cold hardiness is important for nursery stock exposed to variable temperatures in the fall and spring. Potassium is also important in regulating plant water status (11) and may help avoid winter dessication.

The objectives of the study were as follows:

1. To assess the effects of root pruning and wrenching treatments on the morphological and physiological quality of white and black spruce transplants and jack pine seedlings during the final year on the nursery.
2. To assess the effects of potassium fertilizer on bud development and on morphological and physiological quality of white and black spruce transplants and jack pine seedlings during the final year on the nursery.
3. To assess the effects of the root pruning and wrenching and potassium fertilizer treatments on the performance of white and black spruce transplants and jack pine seedlings after outplanting.

Methods

Root conditioning and potassium fertilizer trials. A split-plot design consisting of three root conditioning treatments and two potassium treatments was set up in four blocks in each of a compartment of rising 2+2 white spruce, a compartment of rising 1½ + 1½ black spruce and a compartment of rising 2+0 jack pine at the Thunder Bay Forest Nursery in May 1985. The three root conditioning treatments were

1. Control, no root pruning, or wrenching applied.
2. Early season root pruning followed by wrenching at 21-day intervals.
3. Early season root pruning followed by wrenching periodically to coincide with peak root growth.

Treatment 2 was wrenched four times after pruning whereas treatment 3 was wrenched twice. An additional treatment, consisting of root pruning after shoot elongation (July) followed by wrenching at 21-day intervals, was applied to the black spruce stock because of its small size at 1½ + ½ stage. This treatment was wrenched three times after pruning.

The two potassium fertilizer treatments were

1. Control, 0.0 kg/ha supplemental elemental potassium applied.
2. 75 kg/ha of supplemental elemental potassium applied as potassium sulphate at five times throughout the summer.

Altogether 375 kg/ha (840 ppm) supplemental elemental potassium were applied.

The root pruning was carried out at a depth of 7.5 to 10 cm, using a single, sharp, horizontal blade mounted on a double-acting hydraulic system beneath a tractor. The root wrenching treatments were carried out at a depth of 12 to 15 cm, using a single, blunt blade angled at 35 degrees on the same hydraulic system.

Height growth and root collar diameter were measured on a permanent sample of 25 seedlings per variate at 21-day intervals throughout the growing season. These same seedlings were fall lifted and assessed for standard morphological characteristics (7).

The data were checked for normality using Rankit plots and homogeneity using Bartlett's F-test. Analysis of variance and Tukey's honestly significant difference were used to determine the significance of difference between individual treatments (21).

A sample of black and white spruce stock was fall lifted and overwinter frozen stored at -2 °C in polylined waxed kraft boxes.

Outplanting trials. The outplanting site was located near Great Lakes Forest Products Camp 45, 115 km north of Thunder Bay, ON. The site, which originally supported an aspen (*Populus tremuloides* Michx.), white birch (*Betula papyrifera* Marsh.), balsam fir (*Abies balsamaea* (L.) Michx.), white spruce (*Picea glauca* (Moench) Voss) mix, had been cutover in 1983, then was site-prepared in the fall of 1984 with Young's teeth (20) spaced at approximately 2 m. The site was a loamy sand on a northeast-facing slope with relatively heavy slash and little advance growth. The competition consisted mainly of raspberry *(Rubus ideaus* L.), alder (*Alnus rugosa* (Du Roi) Spreng.), hazel (*Corylus cornuta* Marsh.),and aspen. The stock was lifted early in the spring and placed in cold storage (+ 2 °C) with the overwinter frozen stored stock. Each species was planted in separate trials at 2- by 2-m spacing with four blocks in each trial in May of 1986. A total of 48 plots with 25 transplants in each were established for white and black spruce and 24 plots of 25 seedlings each were established for jack pine. The stock was monitored for survival, height growth, and root collar diameter in the fall of 1986 and 1987.

The field data were analyzed as described above for the nursery trials.

Results

Root conditioning and potassium fertilizer trials. *White Spruce.* The height, root collar diameter, and bud diameter of the white spruce transplants were reduced by root pruning and wrenching (table 1). Initial and final measurements of height and root collar diameter refer to measurements made before outplanting and at the end of the season.

Table 1—*Morphological characteristics of root pruned and wrenched white spruce transplants*

Conditioning treatment	Height (cm)		RCD (mm)		RAI (cm^2)	TDW (g)	RDW (g)	T/R	BD (mm)
	Initial	Final	Initial	Final					
1. Control	12.5	23.3 a	3.2	6.4 a	86	7.3 a	2.9	2.7 a	4.0 a
2. 21 day	11.4	18.3 b	3.1	5.5 b	96	5.3 b	2.6	2.2 b	3.5 b
3. Periodic	11.6	19.5 b	3.1	5.7 b	78	5.8 b	2.5	2.5 ab	3.6 b

Values in columns followed by different letters are significantly different at the 95% level of confidence. RCD = root collar diameter, RAI = root area index, TDW = top dry weight, T/R = top–root ratio, BD = bud diameter; initial refers to measurements before treatment, final to measurements at the end of the season.

No significant difference in mean root dry weight or root area index was apparent between the three root conditioning treatments, but top dry weight was reduced by root conditioning (table 1). Root pruning and wrenching treatments had more effect on the shoots than on the roots of the stock. Top dry weight was reduced by 25%, whereas root dry weight was only reduced by 12% which was not significant. The mean top-root ratio (T/R ratio) of treatment 2 was significantly smaller than that of treatment 1.

All stock was above the minimum desirable standard for shippable 2 + 2 white spruce stock (height, 15 cm; root collar diameter, 3.0 mm; and root area index, 36 cm^2) for Ontario's north central region (14). Only treatment 1 stock reached the objective mean height of 21 cm, even thought root collar diameter and root area index were above the objectives of 3.9 mm and 65 cm^2 respectively.

Supplemental potassium fertilizer had no significant effect on the morphological quality of the white spruce transplants.

Black spruce. Because of the small size of the 1½+ ½ stock, the early season root pruning treatment removed only one to three new root tips per transplant. This treatment was more of a shallow wrenching than a pruning treatment because of the poorly developed root systems of the recently transplanted 1½+ ½ stock.

The height, root collar diameter, and bud diameter of the black spruce transplants were reduced significantly by root pruning and wrenching (table 2). The largest reduction was effected with treatment 2, which was pruned in May and wrenched most frequently. The root pruning and wrenching treatments had no significant effect on the mean root volume or root area index of -the stock (table 2). Top and root dry

Table 2—*Morphological characteristics of root pruned and wrenched black spruce transplants*

Root conditioning treatment	Height (cm)			RCD (mm)		RAI (cm^2)	RTVOL	BD (mm)
	Initial	Final	Growth	Initial	Final			
1. Control	8.7	23.7 a	15.7 a	2.1	5.2 a	73	7.5	2.8 a
2. Early–21 day	8.7	17.8 c	11.4 b	2.1	4.2 c	75	6.6	2.2 c
3. Periodic	8.7	19.3 bc	11.5 b	1.9	4.4 bc	63	5.5	2.5 b
4. Late–21 day	8.9	20.6 b	12.4 b	2.0	4.8 ab	79	7.2	2.5 b

Values in the same column followed by different letters are significantly different at the 95% level of confidence. RCD = root collar diameter, RAI = root area index, RTVOL = mean root volume, BD = bud diameter.

weight measurements were not made for the black spruce stock so top-root ratio could not be evaluated.

All stock was above the minimum desirable standard for shippable 1½+1½ black spruce stock (height, 15 cm; root collar diameter, 2.6 mm; and root area index, 31 cm^2) for Ontario's north central region (14). Not even treatment 1 stock reached the objective mean height of 29 cm, even though mean root collar diameter and root area index were above the objectives of 4.0 mm and 60 cm^2, respectively.

Supplementary potassium fertilizer significantly decreased the root area index (24%) and root volume (17%) of treatment 2 stock.

Jack pine. The height, bud diameter, root collar diameter, top dry weight, and top-root ratio of the jack pine seedlings were significantly reduced by root pruning and wrenching (table 3).

Root dry weight of treatment 2 stock was increased by root pruning and wrenching (table 3). The root area index of treatment 2 stock was also increased but the differences were not significant (table 3).

All stock was above the minimum desirable standards for shippable 2+0 jack pine stock (height, 13 cm; root collar diameter, 2.6 mm; root area index, 20 cm^2) in Ontario's north central region (14). Only treatment 1 stock reached the objective mean height of 18 cm, even though mean root collar diameter and root area index were above the objectives of 3.4 mm and 30 cm^2 respectively.

Supplementary potassium fertilizer had no effect on the morphological quality of jack pine seedlings.

Outplanting performance. *White Spruce*. Survival was high in both years with no significant differences occurring between the root conditioning treatments (table 4). Initially, treatment 1 (control) stock was significantly taller and had larger buds and larger root collar diameters than stock from treatments 2 and 3 (table 1). In the first season after outplanting, treatment 1 stock grew significantly better than stock from treatments 2 and 3. Frozen stored stock grew more than spring lifted stock. By the end of the second season in the field, there were no significant differences in mean height growth between the treatments. Height growth, taken as a percent of initial size, was better for spring lifted root conditioned stock than control stock in both years.

In the first season after planting, treatment 1 stock maintained larger mean root collar

Table 3—*Morphological characteristics of root pruned and wrenched jack pine seedlings*

Conditioning treatment	Height (cm)		RCD (mm)		RAI (cm^2)	TDW (g)	RDW (g)	T/R	BD (mm)
	Initial	Final	Initial	Final					
1. Control	2.9 a	18.7 a	2.3	4.4 a	32	3.5 a	0.7 b	5.2 a	2.5 a
2. 21 day	2.7 ab	15.1 b	2.3	4.1 ab	38	2.8 ab	1.0 a	2.9 b	2.2 b
3. Periodic	2.6 b	14.4 b	2.1	3.8 b	32	2.3 b	0.7 b	3.3 b	2.2 b

Values in the same column followed by different letters are significantly different at the 95% level of confidence. RCD = root collar diameter, RAI = root area index, TDW = total dry weight, RDW = root dry weight, T/R = top-root ratio, BD = bud weight.

diameters than stock from treatments 2 and 3 (table 4). There were no significant differences in mean root collar diameter increment between the root conditioning treatments in the first or second season after outplanting.

Supplementary potassium fertilization had no significant effect on the survival or growth of the white spruce transplants after outplanting.

Black spruce. Survival was high in both years with treatment 2 stock that had been frozen stored having significantly better survival than control stock. Treatment 1 (control) stock was taller than stock from treatments 2 and 3 at the time of planting (table 5). There were no significant differences in height growth between the root conditioning treatments after the first or second season in the field. Overwinter frozen stored stock grew significantly better than spring lifted stock during the first season after outplanting. The mean root collar diameter of control stock remained larger than that of root conditioned stock in both years.

Supplementary potassium fertilization had no effect on the survival or growth of the black spruce transplants after outplanting.

Jack pine. Survival after outplanting was very high in both years. Treatment 1 (control) stock was taller than treatment 2 and 3 stock at the time of planting. There were no significant differences in mean height growth, root collar diameter, or survival between any of the treatments after the first and second growing seasons (table 6). Height growth was better in the second season after outplanting, indicating stock had become established and recovered from outplanting shock.

Table 4—*Height and root collar diameter measurements for root conditioned white spruce transplants in the first and second season after outplanting*

Conditioning treatment	Survival (%)		Height growth (cm)			RCD (mm)		
	1986	1987	Initial	1986	1987	Initial	1986	1987
Frozen stored								
1. Control	98.0	98.0	25.3 a	8.6 a	6.3	6.3 a	7.6 b	7.7 a
2. 21 day	99.0	97.5	21.0 b	6.9 b	5.0	5.6 b	6.5 c	7.0 b
3. Periodic	98.0	96.0	23.3 b	7.2 b	6.2	5.8 b	7.1 bc	7.2 b
Spring lifted								
1. Control	97.5	95.0	27.5 a	7.6 a	5.6	6.5 a	8.2 a	8.0 a
2. 21 day	99.5	99.5	23.8 b	6.4 b	5.7	5.9 b	7.6 b	7.7 a
3. Periodic	99.0	98.5	22.9 b	6.2 b	5.6	6.0 b	7.2 b	7.5 ab

Values in columns followed by different letters are significantly different at the 95% level of confidence. RCD = root collar diameter.

Table 5—*Morphological characteristics of root pruned and wrenched black spruce transplants in the first and second season after outplanting*

Conditioning treatment	Survival (%)		Height growth (cm)			RCD (mm)	
	1986	1987	Initial	1986	1987	1986	1987
Frozen stored							
1. Control	81.0 c	75.5 c	21.2 a	14.5 a	7.6	5.7 a	8.0 a
2. 21 day	91.5 ab	89.0 ab	18.2 b	13.5 a	7.5	5.4 b	7.5 b
3. Late	83.0 bc	83.0 bc	19.9 b	13.9 a	8.7	5.3 b	7.4 b
Spring lifted							
1. Control	92.0 ab	87.5 ab	20.9 a	10.7 b	9.0	5.7 a	7.6 b
2. 21 day	97.0 a	94.0 a	16.3 b	10.5 b	8.9	5.0 b	6.5 c
3. Late	85.5 bc	83.5 bc	19.3 b	10.0 b	8.5	5.3 b	7.2 b

Values in the same column followed by different letters are significantly different at the 95% level of confidence. RCD = root collar diameter.

Table 6—*Morphological characteristics of root pruned and wrenched jack pine seedlings in the first and second season after outplanting*

Root conditioning treatment	Survival (%)		Height growth (cm)			RCD (mm)	
	1986	1987	Initial	1986	1987	1986	1987
1. Control	98.0	98.0	16.4 a	16.4	23.3	5.4	8.9
2. 21-Day	98.5	97.5	14.6 b	17.4	24.1	5.5	9.2
3. Periodic	99.5	98.5	13.5 b	15.6	23.8	5.1	8.6

Values in the same column followed by different letters are significantly different at the 95% level of confidence. RCD = root collar diameter.

Supplementary potassium fertilizer had no significant effect on the survival of jack pine seedlings after outplanting. Fertilized seedlings grew 11% more than unfertilized in the first season after outplanting. By the end of the second season in the field fertilized seedlings were only 7% taller than unfertilized stock.

Discussion

Root pruning and wrenching treatments decreased the height, root collar diameter, top dry weight, top-root ratio and bud size of white and black spruce transplants and jack pine seedlings in the nursery. As the treatments increased or had no effect on root dry weight and root area index, they increased root system size relative to top size.

A major problem with overwinter frozen spruce is reduced survival after outplanting. Root pruning and wrenching treatments appear to have improved the survival of overwinter frozen stored black spruce but had no effect on the survival of stored white spruce stock.

The major problem with jack pine bareroot stock in northern Ontario is excessive height growth in the second year in the nursery. The optimum top-root ratio for jack pine is 3:1 (16). In this study, control stock had a mean top-root ratio greater than 5:1, indicating that the tops were too large relative to root system size. Root conditioning improved the morphology of 2 + 0 jack pine by decreasing the top-root ratio to 3:1.

The season in which the root conditioning treatments were carried out at the nursery was unusually wet (precipitation was 120% of normal) (10). Unusual wetness may be the reason for the small size of the control stock and may also have reduced the degree of stress after pruning and wrenching, so that there was little difference in physiological condition, and therefore the outplanting performance, between the three treatments.

Supplemental potassium fertilizer reduced the root growth of black spruce in the nursery but had no effect on white spruce or jack pine root growth. Excess potassium has been shown to cause root damage in previous studies (8). Supplementary potassium did not improve the outplanting performance of white or black spruce transplants but appeared to improve the growth of jack pine seedlings after outplanting. No previous studies have reported growth increases as a result of potassium fertilizer. It is possible that the potassium fertilizer made the seedlings less susceptible to water stress (11). This would allow them to grow when the unfertilized stock could not.

Conclusions

Root pruning and wrenching can be used as a cultural tool in the nursery to improve the morphology of 2 + 2 white spruce, 1½ + 1½ black spruce and 2 + 0 jack pine stock by decreasing height and increasing root system size.

The effects of these treatments on outplanting success are not yet clear, but the treatments appear to have improved the survival of overwinter stored black spruce transplants. Although root pruning and wrenching treatments have increased survival and growth after outplanting in New Zealand and the Pacific Northwest, in this study they did not significantly improve the performance of white and black spruce transplants or jack pine seedlings after outplanting in northern Ontario (5).

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