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Reducing Botrytis in Container-Grown Western Larch by Vacuuming Dead Needles

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Needles shed during fall from container-grown western larch seedlings can be removed with an ordinary shop vacuum, reducing the potential for Botrytis infection. Nurseries that use this method as part of an integrated pest management system have avoided fungicide treatments for Botrytis. Tree Planters' Notes 43(2):30-32; 1992.

Botrytis cinerea, or grey mold, favors conditions of moderate temperatures, high moisture, and dense foliage, which are frequently found in container nurseries in late summer and fall. Generally, this disease starts on senescent, dead, injured, or lower needles (Sutherland and others 1989). Disease initiation often coincides with the hardening-off phase of western larch *(Larix occidentalis* Nutt.). Falling needles can accumulate to an appreciable depth on top of the blocks. Slow to dry after irrigation, this mat of needles provides excellent conditions for grey mold development. From here, the disease can spread to healthy tissue and degrade stock quality. Packing infected material for cold storage at temperatures above freezing allows the fungus to continue growing, further decreasing stock quality, if not destroying the seedlings (Russell 1990).

Most recommendations for controlling grey mold include lowering relative humidity and increasing aeration to reduce spore germination and further growth of the fungus (Russell 1990; Sutherland and others 1989; Srago and McCain 1989). This can be accomplished by watering less frequently and early in the morning, improving ventilation by spreading the blocks apart, regulating temperature, or some combination of the above. Under-bench, forced-air ventilation also improves aeration and reduces the incidence of disease (Peterson and Sutherland 1990). Some growers also find it helpful to add a spreader to the irrigation water to foster evaporation from the needles and to brush the foliage with a wooden dowel or piece of plastic pipe to gently remove water droplets from the needles. Having shorter target heights and growing seedlings at a slower rate also decreases disease incidence and the need for fungicides (Dumroese and others 1990).

In greenhouses, removing dead material from the growing area to reduce grey mold inoculum is recommended (Sutherland and others 1989; Wenny and Dumroese 1987). Removing the mat of dead larch needles by hand can be a laborious, expensive effort. Workers at North Woods Nursery, Inc., of Elk River, Idaho, and the University of Idaho Forest Research Nursery, Moscow, Idaho, have found an easy way to remove this build-up of dead foliage.

Vacuuming Needles

Workers use a 16-gallon, 2.25-horsepower ordinary wet/dry shop vacuum to remove dead larch needles (figure 1). The vacuum is generally strong enough to remove all the dead needles as well as a grit topdressing (figure 2). This technique also helps keep the greenhouse tidier and reduces the mess of needles that accumulate in the packing shed. Further, it greatly reduces the amount of dead needles packed with the seedlings, reducing the level of *Botrytis* inoculum that could begin to grow during cold storage, causing serious damage.

Vacuuming vs. Fungicides

One worker can clean about 5,700 seedlings per hour. This year, each nursery vacuumed about 100,000 larch seedlings. This procedure was part of an integrated pest management program that included removing dead seedlings, adding a spreader to every irrigation rinse, and brushing off the foliage. The program was so effective that chemical control of *Botrytis* was unnecessary at both nurseries because the fungus was absent or at extremely low levels. Srago and McCain (1989) state the standard preventative spray program for California and the Pacific Northwest uses foliar fungicides applied at 1- to 2-week intervals. If this is done from hardening to late fall, this could result in at least 6 to 12 applications of fungicide. Because *Botrytis* can develop resistance to some fungicides, especially benomyl, it is suggested to use fungicides in rotation to control this disease. The costs of vacuuming were less than

Figure 1—*Worker vacuuming away dead larch needles.*

half those of weekly pesticide spraying (table 1), assuming a Captan 50 WP, Benlate 50 WP (benomyl), Botran 75 W (DCNA) chemical rotation was applied at a rate of 1, 0.5, and 1 pound of fungicide (respectively) per 100 gallons, and 200 gallons were applied each time.

Management Implications

Vacuuming senescent larch needles in early fall, as one component of an integrated pest management plan, can reduce or eliminate the need for chemical fungicide treatments. This treatment seems cost-effective compared to a preventative foliar fungicide spraying program (table 1). Such intensive preventa-

Table 1—*Costs of one-time vacuuming of 100,000 larch seedlings compared to applying foliar fungicides at 1- or 2-week intervals*[1]

	Vacuuming	Fungicides weekly	Fungicides every 2 weeks
Chemical costs[2] ($)	0	144	72
Hours of labor[3]	17.5	6	3
Labor costs[4] ($)	88	48	24
Total costs ($)	88	192	96

[1] Assumes six 2-week interval or twelve 1-week interval fungicide applications for 12 weeks to 100,000 western larch, using 200 gallons of solution applied with a travelling boom irrigation system.

[2] Assumes the following costs: Captan at $2.29 per pound, benomyl at $16.34 per pound, and Botran at $7.47 per pound.

[3] Assumes vacuuming 5700 seedlings per hour and 30 minutes to mix and apply fungicides.

[4] Assumes vacuuming done by seasonal employee paid $5 per hour and fungicides applied by permanent staff at $8 per hour.

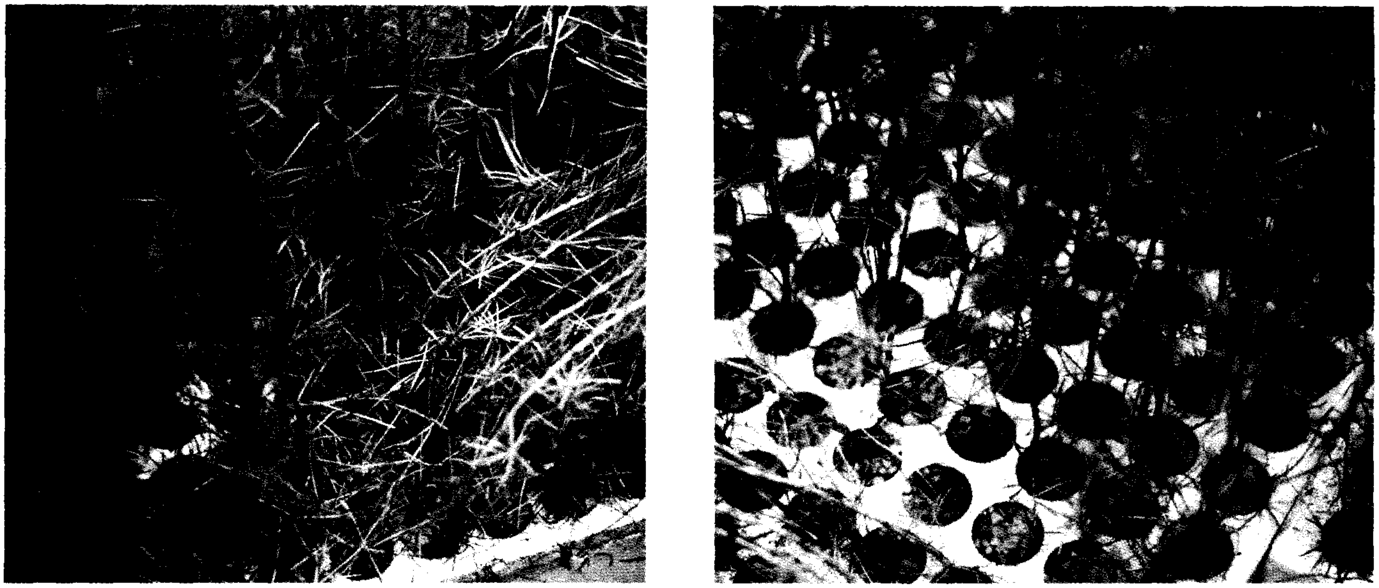

Figure 2—*Seedlings showing mat of dead larch needles before vacuuming* (**left**) *and afterward* (**right**).

five spray programs are not necessarily needed (Dumroese and others 1990) and will become increasingly hard to maintain as concerns arise over nursery waste water (Dumroese and others 1991). Besides removing needles, vacuuming eliminates problems associated with chemical applications, including waste water, worker exposure, and development of fungal resistance to the chemical.

Acknowledgments

We thank Marla and Jim Schwartz of North Woods Nursery, Inc., for sharing information with us. We also thank Kenneth E. Quick of the University of Idaho Forest Research Nursery for keeping good records and keeping the facility neat.

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Increasing Hardwood Seed Quality With Brush Machines

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Poor seed quality often adversely affects the cost and efficiency of producing hardwood seedlings. The lack of a good method to husk and de-wing seeds and break up clusters prevents many nurseries from upgrading hardwood seeds. Trials with a laboratory model brush machine showed that seed quality for several species of hardwoods could be improved. Tree Planters' Notes 43(2):33-35; 1992.

Many hardwood seeds are winged or in clusters or fruits that make conditioning and mechanical planting difficult to impossible. Planting such seeds mechanically results in poorly regulated bed densities; planting them by hand can be prohibitively expensive. The USDA Forest Service's National Tree Seed Laboratory in Dry Branch, Georgia, tested a laboratory model brush machine to determine if it could de-wing yellow-poplar and ash, break up dusters of ash and maple, and hull winterfat seeds.

Materials

A brush machine is basically a wire cylinder with brushes inside it that rub the seeds against the inside of the cylinder (figure 1-3). The wire cylinder is oval in cross section, so that the seeds can roll and come under the brushes, and the wire in the cylinder is

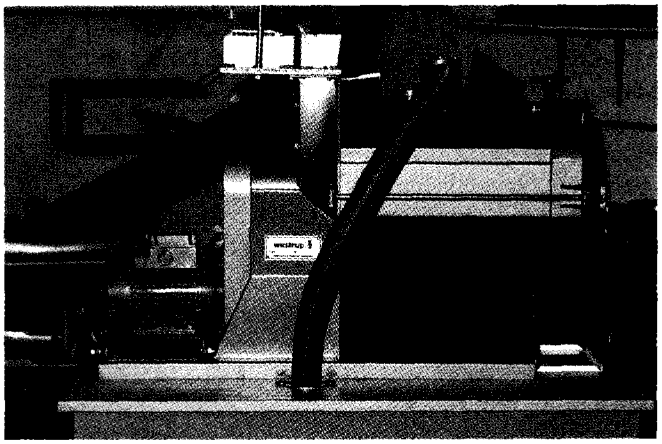

Figure 1—*Laboratory model of brush machine. Seeds are fed in on the top (see figure 2) and discharged on the right.*

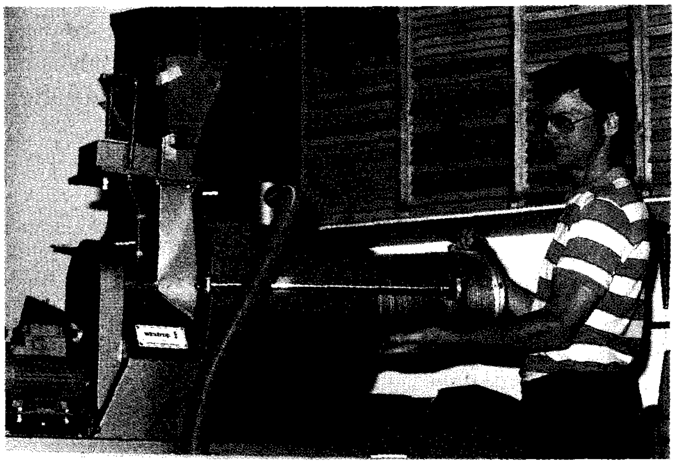

Figure 2—*The seeds are rubbed by brushes against a wire cylinder called a shell. Here, the shell is being removed from the machine for cleaning.*

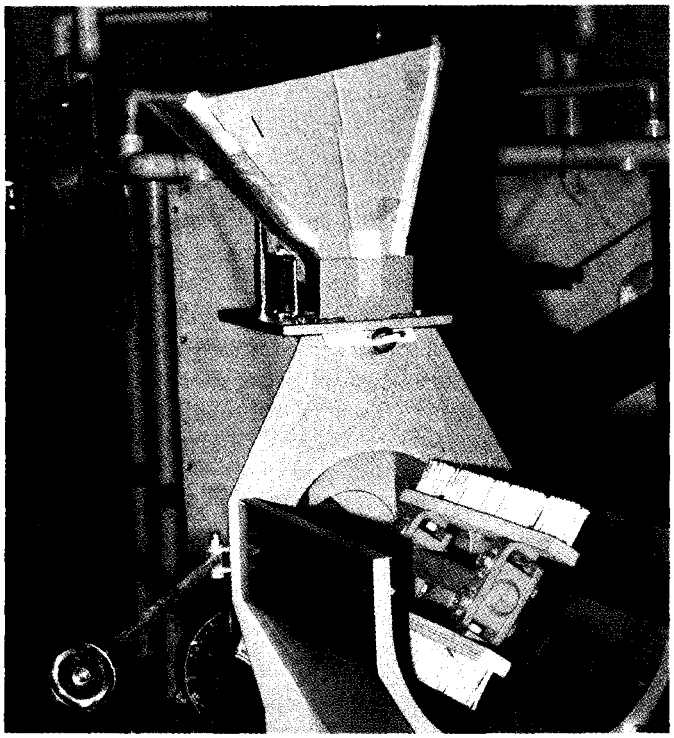

Figure 3—*These brushes rub the seeds against the inside of the shell shown in figure 2. The brushes come in several degrees of stiffness. The closeness of the brushes to the shell is called the tension and is adjustable.*

usually square instead of round, so that the cutting action of the brush is improved. Brushes vary in stiffness, with stiffer brushes providing more abrasion than softer ones. The space between brushes and cylinder is adjustable, as is the rate at which the brushes revolve. Stiffer brushes, higher brush tension (less clearance between brushes and the cylinder), and faster brush rotation give faster hulling but also greater chance for seed injury. Opening and closing the discharge gate regulates the length of time the seed remains in the machine. All brush machines should have good aspiration to control the dust produced by the hulling operation.

Seeds from white ash *(Fraxinus americana* L.), yellow-poplar *(Liriodendron tulipifera* L.), sycamore *(Platanus occidentalis* L.), and red maple *(Acer rubrum* L.) were acquired from trees in the middle Georgia area. Seeds from winterfat *(Ceratoides [Eurotia] lanata* (Pursh) Moq.), a range shrub, were supplied by the Lucky Peak Nursery in Boise, Idaho.

The potential of the brush machine to condition these seeds was tested with a laboratory model. Brushes of varying stiffness, different amounts of brush tension, varying speed, and multiple passes through the machine were evaluated.

Results

White Ash. The samaras of white ash were easily pulled apart by the machine, and the wings could be completely removed without any apparent damage to viability as evaluated by standard germination procedures (AOSA 1990) (table 1, figure 4). Neither brush tension nor the number of passes through the machine was highly critical, as seen by the apparently equal viabilities of single-pass samples and multiple-pass samples. Faster germination appeared to be associated with the more abrasive treatments. Probably this was the result of slight tearing of the seed coat, which would promote release of the germinating embryo.

Yellow-poplar. The dry cones of yellow-poplar were quickly broken apart in the machine. The wing was easily removed, making it possible to remove most of the empty seed on the specific-gravity table. Two lots of poplar seed were tested. One, collected from a parking lot gutter where it had weathered some, was de-winged in one pass. A second lot was not weathered and required two trips through the machine. The second trip was needed to completely remove the rib of the wing. Viability was not evaluated.

Red maple. The samaras of red maple could be separated out of the clusters but were easily damaged. Soft hair brushes had to be used to minimize damage. De-winging was not possible without some tearing of seed coats. Because the original viability of this seed lot was poor, the machine's effect on viability could not be evaluated accurately.

Sycamore. Dry sycamore fruit heads quickly shattered, and the hairs brushed cleanly from the seed in one pass. The aspiration feature of the brush machine did an excellent job of controlling the highly irritating dust of the sycamore. Because this seed lot was taken from a single isolated tree that did not produce any filled seed, viability could not be evaluated for this species.

Winterfat. The difficult seeds of this species were hulled very effectively by the brush machine. The seeds were removed from the bulky, clumping fruit with apparently minimal damage. A few seeds were broken, but x-ray and microscopic examination showed no damage to the intact seeds. The seed lot used in this trial was nonviable, and the effect of treatment on germination could not be evaluated.

Discussion

The results here show promise for improving the quality of hardwood seeds, thus enabling nursery managers to plant difficult seeds mechanically. This is made possible by the brush machine, which can break up seed clusters, remove wings, and hull seeds out of the fruits. White ash seeds, the only ones that could be tested for viability, showed very high viability, even with the harsher treatments.

Successful de-winging of yellow-poplar was accomplished by Bonner (1971) using a debearder. Springfield (1974) reported using a hammer mill to husk winterfat. The brush machine is expected to be superior to these two devices because it results in less mechanical injury to the seed. Because hulling operations involve tearing and cutting, some level of damage is expected, but it can be minimized by careful adjustment of the machine. Seeds of other species, such as grasses and tomatoes, can be husked or polished in brush machines without serious loss of viability. Careful use of the machines should also help improve trees and shrub seed quality. Further evaluations will be made as viable seeds of different species are made available to the laboratory.

Table 1—*White ash de-winging treatments with brush machines*

Sample no.	Brush type	Brush tension	Brush speed*	No. of passes	Germination percent	
					28 days	35 days
1	Unde-winged	Control sample	—	—	57	94
2	Soft	Not touching	¾ Full	1	67	93
3	Soft	Not touching	¾ Full	2	78	96
4	Soft	Not touching	¾ Full	3	93	95
5	Soft	Not touching	¾ Full	6	95	97
6	Soft	Just touching	Minimum	4	92	94
7	Soft	Just touching	¾ Full	1	91	95
8	Soft	Just touching	¾ Full	2	91	95
9	Soft	Just touching	¾ Full	3	92	93
10	Soft	Just touching	Full	1	72	90
11	Soft	Fairly tight	Full	1	90	93
12	Soft	Tight	¾ Full	1	85	98
13	Soft	Tight	¾ Full	2	83	94
14	Stiff	Fairly tight	Full	1	86	92
15	Stiff	Fairly tight	¾ Full	1	84	91
16	Stiff	Fairly tight	¾ Full	2	90	94
17	Stiff	Fairly tight	¾ Full	3	87	92

*Brush speed is how fast the brushes were turning. A speed of ¾ full = a speed control setting of ¾ of maximum speed. Minimum brush speed = a speed control setting of minimum.

Figure 4—*Seeds of white ash can be singularized and de-winged in the brush machine. Samaras in clusters* (**left**)*: singularized samaras* (**center**)*; samaras with wing removed* (**right**).

Sources

To the best of the author's knowledge, there are three suppliers of brush machines in the United States:

Carter-Day Company
500 73rd Avenue, NE
Minneapolis, MN 55432
telephone: (612) 571-1000

Westrup, Inc.
1400 Preston Road
Plano, TX 75093
telephone:(214) 985-7887

Hendrickson Enterprises
4050 NE Minnesota Avenue
Corvallis, OR 97330
telephone: (503) 757-8019

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Comparing a Spray Boom to a Roller-Wiper System for a Single-Passenger Four-Wheeler

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The ability of spray booms and carpet-covered roller-wipers mounted on four-wheelers to apply herbicides on pine planting sites was tested with the following treatments: spray boom application of 0.31 kg (0.69 lb) acid equivalent glyphosate with 0.08 kg (0.18 lb) active ingredient sulfometuron in 215 liters of water/ha (23 gallons/acre) and roller-wiping the vegetation with a solution of 1 % glyphosate and 0.1 % sulfometuron in water. Both application methods controlled herbaceous plants, but the spray boom was more effective than the roller-wiper: weed control averaged 94% on sprayed plots and 63% on wiped plots compared to untreated controls. Apparently, unless modified, the roller assembly is not a practical alternative to the spray boom unless drift must be kept minimal. Tree Planters' Notes 43(2):36-38; 1992.

Single-passenger four-wheelers can be used to apply herbicides on forest sites. The driver can spot-treat with a spray gun or granular applicator to avoid broadcasting the herbicide. However, broadcast or banded applications of herbicides over or between rows of planted seedlings may be a better option than spot treatments.

Sponge bar, roller-wiper, or spray boom systems can be used to broadcast or band herbicides. Wiping places the herbicide more selectively than spraying and reduces drift because small droplets are not formed. Almost no off-site movement of the herbicide should occur with wiping if the herbicide is nonvolatile and adsorbed readily in the soil. One widely used herbicide that meets these criteria is glyphosate–N-(phosphonomethyl)glycine.

A small-scale herbicide application system designed to be mounted on a single-passenger four-wheeler might include either a spray boom or a roller-wiper. Because of the important need to find herbicide applications that minimize drift, we compared the field performance of a 6-foot spray boom mounted with five fan nozzles to that of a carpet-covered roller-wiper for controlling established herbaceous vegetation prior to planting pine seedlings.

Methods

Study site and equipment calibration. The study was done in Rapides Parish, Louisiana, on a site where herbaceous weed control was needed before outplanting. The vegetation was primarily bluestem (*Andropogon* spp. and *Schizachyrium* spp.) and panicum (*Panicum* spp. and *Dichanthelium* spp.) grasses, pinehill beakrush *(Rhynchospora globularis* (Chapm.) Small), eupatoriums (*Eupatorium* spp.), sunflowers (*Helianthus* spp.), catclaw sensitive brier (*Schrankia uncinata* Willd), asters (*Aster* spp.), blackberry (*Rubus* spp.), and Japanese honeysuckle (*Lonicera japonica* Thunb.).

Before treatment, the spray boom was calibrated to determine the actual spray swath and flow rate through the fan nozzles. Boom height was adjusted to ensure proper overlapping coverage between nozzles, and the five nozzles were evenly spaced 0.45 m (1.5 feet) apart along the boom. Total spray swath was 2.3 m (7.6 feet), and the flow rate through the five fan nozzles was 2.3 liters (0.6 gallons) per min. For the roller-wiper treatment, actual dosage depended on the degree of contact with the vegetation. The roller-wiper was 1.2 m (4 feet) wide (figure 1).

Treatments. Five blocks of three 20-m-long (66-foot) and 2.4-m-wide (8-foot) plots were established in a randomized complete block design (5 blocks x 3 treatments). Blocking was based on drainage and changes in species composition of the vegetation. There was a 2.4-m (8-foot) buffer between plots within and between blocks.

We tested the following treatments:

1. Untreated controls
2. Spray boom application of 0.31 kg (0.69 lb) acid equivalent glyphosate with 0.08 kg (0.18 lb) active ingredient sulfometuron--2-[[[[(4,6-dimethyl-2-pyrimidinyl)amino] carbonyl]amino]sulfonyl]benzoic acid--in 215 liters water/ha (23 gallons/acre)

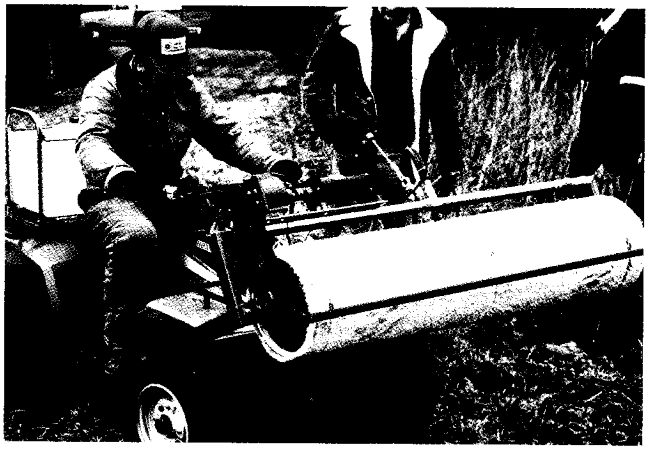

Figure 1—*Single-passenger four-wheeler mounted with a carpet-covered roller-wiper assembly. An electric motor turns the drum during application, and the chemical is added from a drip pipe mounted above the roller. The tank is mounted on the rear of the four-wheeler.*

3. Roller-wiping of the vegetation with a solution of 1% glyphosate and 0.1% sulfometuron in water (figure 1).

The herbicide compositions in treatments 2 and 3 are identical. We present the component amounts in different formats because the exact rate used in treatment 3 (roller-wiper) depended on the amount of contact between the roller-wiper and the vegetation itself. The chemicals were applied on May 1, 1990.

Treatments 2 and 3 involved a single pass over the entire length of the plot. The spray boom and roller applications began at 7:15 am and ended at 8:05 am. The wind was calm and there was no rain that day.

Side test. During treatments with the rollerwiper, it became apparent that the system needed a monitoring device to determine the saturation of the roller. As designed, the carpet roller had to be infused with a steady flow of herbicide solution and subsequently, the roller unexpectedly used more liquid per acre than the spray boom did. An additional trial was carried out to determine how long the roller would hold sufficient residual herbicide to control weeds adequately once the pump was stopped and no more chemical was added to the roller. The roller mechanism was continuously rotated in the side test, and a continuous transit was made over vegetation and terrain similar to that found in the formal study.

Measurements and data analysis. On June 7, 1990, the percentage of vegetation control was estimated for each plot. These percentages were based on the reduction in plant cover between the treated band and adjacent untreated vegetation. The determinations were made beginning at 0.9 m (3 feet) from the end of the plot and then every 1.8 m (6 feet) for the 20.1-m (66-foot) length of the plot. The 11 sample points (in size 1.03 m2 or .00025 acre) per plot were averaged, and the plot averages were compared by analysis of variance ($P < 0.05$) and orthogonal comparisons of 1. untreated check versus spray boom + roller-wiper and 2. spray boom versus roller-wiper.

Results and Discussion

Both application methods controlled the vegetation, but the spray boom was more effective than the roller-wiper (table 1). On the sprayed plots, weed control averaged 94% (reduction in weeds compared to controls) and ranged from 89 to 97% across blocks. On the wiped plots, weed control averaged 63% and ranged from 11 to 85% across blocks.

The wide range in weed control on the wiped plots occurred because the roller did not contact enough of the vegetation when the terrain changed slightly, causing the roller to kick up on one side or to pass above the vegetation. Also, the roller-wiper often did not come into contact with vegetation that was shielded by the taller grasses as the roller pushed the grass over. This was a serious problem later in the season as these escaped plants developed.

A flexible roller or a jointed and flexible roller assembly might increase contact with the vegetation by allowing the roller to move down as the terrain changes. Mowing the cover or treating the plant cover earlier in the growing season, while the vegetation is shorter, might increase contact as well.

The roller treatment created a narrower band of controlled vegetation than the spray boom treatment did. Roller-wiping resulted in about a 1.2-m-wide (4-foot) band and spraying resulted in a 2.1-m-wide (7-foot) band of effectively controlled vegetation.

Table 1—*Percentage of herbaceous plants (weeds) killed by spray boom and roller-wiper application of glyphosate and sulfometuron, by blocks (#1–5)*

	% Reduction in herbaceous plants*					
Treatments	#1	#2	#3	#4	#5	Mean
Untreated controls	0	0	0	0	0	0
Spray boom	97	94	89	94	95	94
Roller-wiper	11	85	71	69	81	63

*Compared to untreated controls.

The spray boom treatment therefore increased production by 75% over the roller treatment. However, a 2.1-m (7-foot) swath may be no more desirable than a 1.2-m (4-foot) swath when herbicide use is limited to narrow bands in which the seedlings will eventually be planted rather than broadcast over the whole site.

The side-test. In the informal side-test, weed control began to decrease after 18.3 m (60 feet) of transit once the pump was stopped and the rotating drum was no longer infused with a steady flow of herbicide solution. About 50% control was obtained for a distance of 60.9 m (200 feet). By the time the four-wheeler had gone 100.6 m (330 feet), weed control was only 30%. No weed control was apparent after 140 m (460 feet).

Conclusions

The roller treatment controlled the contacted vegetation even though a low concentration of herbicide solution was used. The problem with the roller-wiper was its inability to contact enough vegetation because the wiper rode over plants when the four-wheeler was not level and overlapping plants often shielded others from contact. Without modifications, the roller assembly is not a practical alternative to the spray boom unless drift must be minimal. For example, drift control is especially important near property lines and near sensitive areas within a property.

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Soil Texture Influences Seedling Water Stress in More Ways Than One

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White spruce (Picea glauca (Moench) Voss) seedlings were planted in pans filled with soils of three different textures: two mineral and one organic (peat). A few months were allowed for adequate root growth into the surrounding medium. After a drying period, transpiration, stomatal conductance, and xylem water potential were measured on all seedlings. For any given level of soil water tension, coarse soil (peat) caused the seedlings to have a lower (more negative) level of water potential than fine soils (fine sand and sandy loam.) Peat was worse than fine sand, and fine sand was worse than sandy loam. The results show that site assessment for planting suitability must take into account the dynamic interaction between soil texture, water supply, and evaporative demand. Tree Planters' Notes 43(2):39-42; 1992.

When a seedling is planted in the field, it immediately starts transporting water from the soil to the atmosphere. While doing so, the water inside the seedling comes under tension as energy is required to extract additional water from the soil. One question of great interest to seedling specialists is the level of internal water tension the seedling must endure in the field. The importance of this question stems from the direct association between internal water tension, cell turgor, and seedling survival and growth.

Soil texture influences the internal level of plant water tension in two ways. The first one is a static influence, the second is a dynamic one. The static influence of soil texture on plant water tension is due to the direct control of texture on the level of water tension in the soil, or soil water potential. For a given water content, fine soils such as clays will have lower (more negative) soil water potentials than coarser soils such as loams and fine sands. In order for water to move from the soil into the plant, the energy level of the water inside the plant must be lower than that of the soil, as in any pumping system. Therefore, fine soils will produce a lower base level of water potential in seedlings than coarse soils.

The second influence of soil texture on plant water tension involves feedback from the plant to the soil. As a root extracts water from the surrounding soil, the water content in the soil at or near the soil-root interface drops, causing a corresponding drop in soil water potential of that near-root zone. The level of soil water potential in the near-root zone will depend on the level of water demand by the root. It will also depend on the ability of the soil further from the root to replenish the lost soil water around that root. Thus, in a dynamic world, properties like water content and hydraulic conductivity at a given soil water tension are also of great importance in determining the level of water tension in the plant. This fact has long been known to soil physicists and agriculturists (for example, Gardner 1960 and Cowan 1965). However, in seedling ecophysiological work, only a few researchers (Dosskey and Ballard 1980) ever consider the role of soil texture in the dynamic soil plant relation as a major influence on the plant's internal water potential. The intent of this report is to document, using white spruce seedlings, the effect of soil texture on internal plant water status during active transpiration. Also shown are computations of soil water potential at the soil root interface.

Methods

Winter-sown containerized white spruce (*Picea glauca* (Moench) Voss) seedlings were obtained from a nursery near Quebec City in late fall. The seedlings had an average height of 15 cm. Initial cavity volume of the containers was 50 cm^3. The seedlings were planted in plastic pans (60 cm by 15 cm by 10 cm), 10 seedlings to a pan. The pans were filled with one of the following soil types (listed in order of increasing particle size): a sandy loam (25% silt, 5% clay), a fine sand (7% silt, no clay), and a commercial fibric peat (the coarsest soil) similar to what is commonly used in containerized production of conifer seedlings. Six pans were used for each of the two mineral soils. Twelve were used for the peat. Moisture release curves were derived for each of the three soils using the pressure plate apparatus. These curves relate the soil water content to the level of water tension. The pressure plate apparatus is a pressure vessel and ceramic plate system that permits water extraction from soils at known tensions. The methods for this procedure are detailed by Klute (1986). The curves for all three soils are shown in figure 1.

The pans with the seedlings were placed in a greenhouse in cool, short-day conditions (15 °C, 9-h day) to prevent bud break but still allow root growth. Precalibrated gypsum blocks were placed in each pan and read three times a week. Water was added as needed to maintain the soil water tension above - 0.1 MPa in all the pans. Soil surfaces were covered with plastic mulch to minimize soil evaporation. Gravimetric soil samples were used to verify gypsum block readings. Readings obtained with the gypsum blocks are referred to as bulk soil water tension (ψ_s bulk), meaning that they represent the average soil water tension in each of the pans.

The seedlings were kept well watered for 2 months to allow for adequate root growth from the original root plug into the surrounding medium. After that period, a 5-day drying treatment was applied during which individual pans were hand-watered with amounts of water calculated to bring each pan as near as possible to a specific soil water tension target. In this way, a range of soil water tensions was obtained for each of the two mineral soil types, and, to a lesser extent, for the peat (figure 2).

On the day preceding the measurements, air temperature was raised to about 20 °C. Three pans, one per soil type, were selected randomly as controls and were watered to near zero soil water potential. The following day, needle conductance and xylem pressure potential were measured on all seedlings between 11 am and 1 pm. Needle conductance, a measure of stomatal opening, was determined using a Li-Cor LI-1600 steady state porometer (Li-Cor, Inc., Lincoln, Nebraska). Xylem water potential, a measure of plant water tension, was obtained with a PMS pressure chamber (PMS Instruments Co. , Corvallis, Oregon). At the time of measurement, temperature, relative humidity, and photon flux density in the photosynthetically active wavelengths (PAR) in the greenhouse were 21 °C, 30%, and 1,100 µmol/m^{2}s. One pan filled with fine sand was discarded; excessive dryness had caused heavy damage and mortality among seedlings. Projected needle surface areas needed to correct the porometer readings were measured with an image analyzer.

In addition to these measurements, soil water potential at the soil-root interface was computed using a method proposed by Jones (1983). Soil water potential at the soil-root interface of the droughted plants was computed from measurements of stomatal conductance and xylem pressure potential of the droughted plants, and of the control plants that had just been well irrigated and were subjected to the same atmospheric conditions:

$$\psi_{s(d)} = \psi_{x(d)} - \psi_{x(i)} \times \frac{g_{n(d)}A_{(d)}}{g_{n(i)}A_{(i)}} \qquad (1)$$

where ψ_s is soil water potential at the soil-root interface (MPa), Ψ_x is xylem water potential (MPa), g_n is needle conductance (cm/s), A is leaf area (cm^2), and the *d* and *i* subscripts refer to the droughted and irrigated plants. Details on the derivation of the model are given in Jones (1983). A Scheffé's test (Freese 1974) was used because of unequal sample sizes to determine significant differences between soils for new root growth.

Results and Discussion

The moisture release curves for each of the three soils (figure 1) reflect the textural differences between the three soil types. These textural differences also affected roots growing out of the original peat plug into the soil during the period of adequate watering. Average dry weight of new root growth was 0.051 g in the fine sand, 0.041 g in the sandy loam, and 0.105 g in the peat. The coefficient of variation was 45%. Scheffé's test revealed that new root growth in the peat was significantly higher ($P< 0.05$) than that in either of the two mineral soils. Low soil densities, as found in fibric peat, are known to promote root growth in conifers under adequate watering (Örlander *et al*. 1990, Prévost and Bolghari 1990).

At the end of the drying period, all measured midday xylem water potentials (ψ_x) were lower (more negative) than the measured bulk soil water tensions (figure 2). However, ψ_x, of seedlings in coarse soils were lower than ψ_x of seedlings in fine soils for the same level of bulk soil water tension. Figure 3 shows soil water tensions at the soil-root interface, computed using equation 1, plotted against the measured bulk soil water tension. The results of this computation show a pattern of response very similar to that shown in figure 2, a normal occurrence since

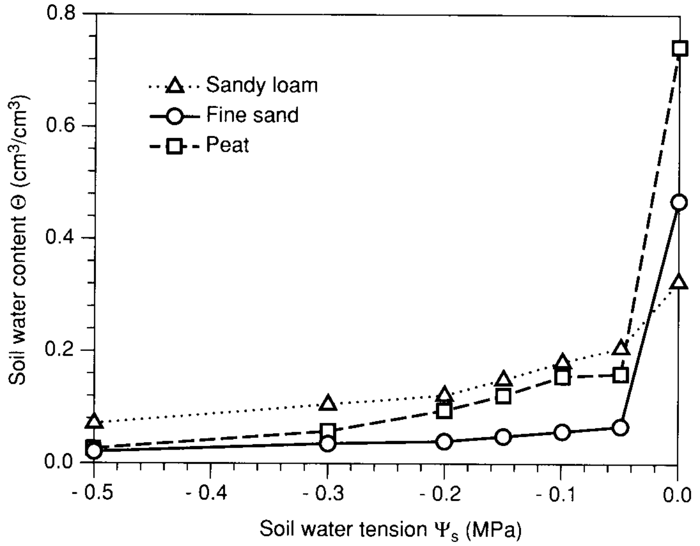

Figure 1—*Soil moisture release curves for the three soils used in the experiment.*

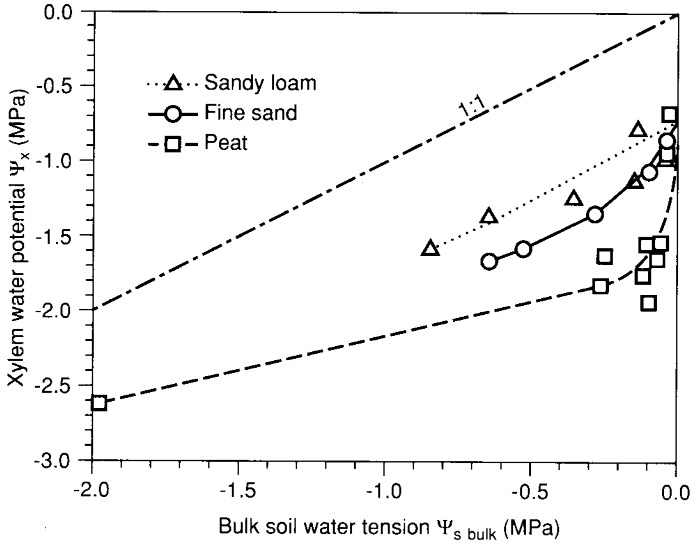

Figure 2—*Xylem water potential in white spruce seedlings* (ψ_x) *versus soil water potential measured with gypsum blocks* ($\psi_{s\ \mathrm{bulk}}$) *in fine sand, sandy loam, and peat during active transpiration. Each point represents an average of 10 seedlings; the curves are hand fitted.*

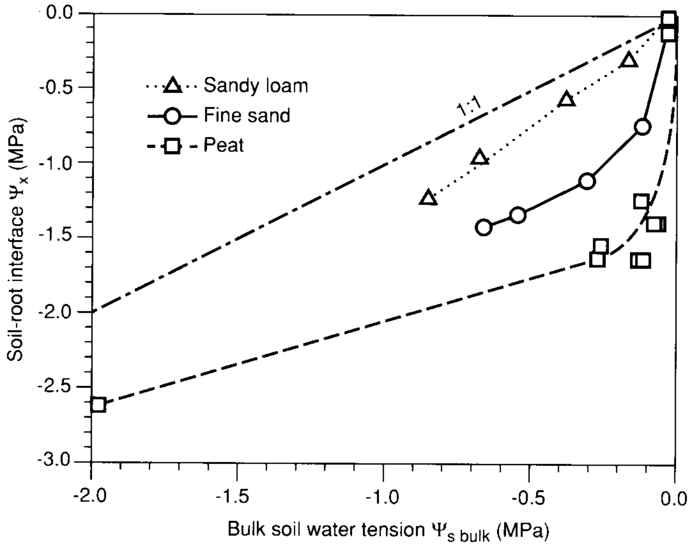

Figure 3—*Computed soil water tension at the soil–root interface* (ψ_s) *versus soil water potential measured with gypsum blocks* ($\psi_{s\ \mathrm{bulk}}$) *for white spruce seedlings planted in three different soils. Each point represents an average of 10 seedings; the curves are hand fitted.*

the computation of near-root ψ_s relies heavily on the seedlings' internal Ψ_x

The results show that, unless they are very moist, the coarser soils in this experiment cause a greater water stress in seedlings than finer soils when the seedlings are actively transpiring. Computations of soil water potential at the soil-root interface show that most of the effect is external to the seedlings and takes place in the soil in the near-root zone. This vote against coarse soils goes somewhat against the static measurement of soil water tension since, for any given volumetric water content, coarse soils hold their water more loosely than fine soils. But, as they dry, the coarse soils lost their ability to move water to the near-root zone faster than fine soils. With all the larger pores drying out first, water transfer in drying coarse soils must be done through increasingly tortuous routes. In the extreme case of highly porous peat, water films may even become disconnected altogether and cease to move anywhere in the liquid phase, whatever tension the seedlings might be under. This is why the peat causes a greater drop in seedling water tension than either mineral soil (figure 2) even though its moisture release curve (figure 1) suggests a more intermediate response.

On the other hand, drying finer soils retain a greater number of smaller pores filled with water and capable of delivering water to the near-root zone. Thus, transpiring seedlings in drying finer soils remain at higher (less negative) levels of internal water tension than they would in coarser soils for the same level of soil water extraction. However, too many fine pores may be too much of a good thing as very fine soils, such as clays, pose a new set of problems for seedlings, including low hydraulic conductivities at any water content, low root penetrability, and low aeration.

Summary

So, based upon these data, which is better for the seedlings, coarse soils or fine soils? It all depends on how much water there is and how much the plant is transpiring. In nurseries, where water contents are kept high, coarser soils offer the advantages of aeration, low bulk density, and ease of water extraction by the seedlings (the first influence of soil texture). However, as nursery managers know well, sand and peat, in particular, must be kept quite wet in order to keep the seedlings growing. In the field, however, soil water content is often far from optimal. Seedlings must transpire if they are to keep their stomata open for CO_2 absorption. The water status around their roots therefore becomes critical, and soils with a greater degree of fine particles, such as loams, present a definite advantage for the seedlings (the second influence of soil texture). Therefore, when assessing a site for planting, one has to consider both soil texture, drainage, and possible water demand by the seedling. The coarser soils used in this experiment are better in areas of good moisture supply. On sites where a higher seedling water demand is expected or water supply is not optimal, finer soils might benefit the seedling. Measurements of soil water tension, although useful, offer only a partial view of soil texture influence on seedling water tension. The results of this experiment should apply to other soils because of the high repeatability of such experiments dealing with physical systems. However, the level of reactions shown here by white spruce might not be the same for all species because of differences in root growth and other physiological properties.

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Comparative Growth of Black Spruce Container Seedlings Grown in Worm-Casting-Amended Soilless Media

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Black spruce (Picea mariana (Mill.) B.S.P.) container seedlings grown in peat vermiculite amended with pig manure worm castings at two concentrations and sewage sludge worm castings at three concentrations were compared with and without fertilization to seedlings grown in peat-vermiculite without amendments. In general, we found that non-fertilized seedlings grown in medium amended with 10% pig manure castings showed the best growth of any of the seedlings. Concentrations of foliar macroelements and microelements (except zinc) were within an acceptable range for container seedlings. Tree Planters' Notes 43(2):43-47; 1992.

Organic soil amendments are commonly used in nursery soils to reduce bulk-density, increase water and nutrient-holding capacities, and change the relative availability of nutrient elements (Armson and Sadreika 1974). Composted sewage sludge, an abundant waste product rich in nitrogen, has been evaluated as an amendment to nursery soils (Coleman *et al*. 1987) and to soilless mixes used in producing containerized nursery stock (Smith and Treaster 1985).

One method of composting, **vermicomposting,** uses earthworms to treat organic wastes, such as sewage sludge and manure. Earthworms break down complex substances in waste material by digestion and their feeding enhances microbial action through aeration (Hamilton et al. 1988). Worm castings are an inexpensive alternative to commercial fertilizers and contain substances that favor root growth and plant development (Grappelli *et al*. 1985). However, sewage sludge is also a potential source of toxic heavy metals that are not always removed during composting (Coleman *et al*. 1987).

This study compared the morphology of containerized black spruce (*Picea mariana* (Mill.) B.S.P.) seedlings grown in fertilized and non-fertilized worm-casting-amended media to seedlings grown in anon-amended fertilized peat-vermiculite mix. The comparison was made to determine if various media amended with castings could produce seedlings equivalent to those produced using a standard nursery growing medium.

Material and Methods

Black spruce seeds from northern Ontario site region 3E (Hills 1960) were sown in 12 Fh 408 Japanese Paperpot® trays and germinated in a greenhouse at the Ontario Ministry of Natural Resources Provincial Forest Tree Nursery at Swastika (Lat. N 48° 06', Long. W 80° 06') on May 25, 1982.

The growing media consisted of a standard peat-vermiculite mix (3:1 by volume) amended as shown (table 1). In addition to a non-amended control treatment, there were two amendments using pig manure castings (10% and 30% by volume) and three amendments using sewage sludge castings (10%, 30%, and 50% by volume). Castings were obtained from Shamrock Industries (Norwich, Ontario).

Seedlings were grown under 2 fertilization regimes. One group was fertilized according to a normal production schedule. Under this schedule, seedlings were fertilized once with 75 ppm nitrogen (10:52:10, N:P:K, Plant Products Co. Ltd.) when the primary needles emerged and 150 ppm nitrogen (20:8:20 N:P:K, Plant Products Co., Ltd.) with every subsequent watering. The second group of seedlings was not fertilized during the trial. However, these seedlings were accidentally fertilized with 75 ppm nitrogen (10:52:10 N:P:K) once at the start of the trial. In total, the 2 levels of fertilization and the 6 media types accounted for 12 treatments, one paperpot tray per treatment. Seedlings grown with various worm casting amendments (table 1) were contrasted with each other and treatment FN, which represented normal production seedlings grown operationally in non-amended peat-vermiculite media and fertilized on demand according to a normal production schedule.

Table 1—*Chemical analyses of worm-casting-amended peat–vermiculite (3:1 by volume) nursery mixes*

Treatment	Code	Total %N	Inorganic nutrients (ppm) P	K	Ca	Mg
Unfertilized						
Control (mix only)	NFN	.433	105	445	3,875	1,884
Pig manure castings						
10%	NFP_{10}	.577	402	433	5,413	936
30%	NFP_{30}	.950	744	640	8,318	986
Sewage sludge castings						
10%	NFS_{10}	.795	569	498	7,963	1,142
30%	NFS_{30}	1.548	715	728	11,160	1,113
50%	NFS_{50}	1.465	984	855	12,528	1,088
Fertilized						
Control (mix only)	FN	.488	303	820	2,875	1,294
Pig manure castings						
10%	FP_{10}	.933	569	896	5,400	904
30%	FP_{30}	1.070	919	995	9,388	974
Sewage sludge castings						
10%	FS_{10}	.865	766	825	7,595	1,025
30%	FS_{30}	1.300	1,141	1,033	10,913	1,066
50%	FS_{50}	1.660	1,238	1,123	12,368	1,046

The trial was carried out in an operational greenhouse. The 6 treatments were randomized within the two fertilization regimes, but the two fertilization treatments were separated in the greenhouse. Although the treatments and seedlings within treatments were not completely randomized, it was felt that the partially randomized design was acceptable given the high degree of uniformity in growing conditions throughout the greenhouse.

Seedlings were moved outside in preparation for overwintering on August 5th, about 10 weeks after sowing. At that time 125 seedlings were randomly sampled from about 290 seedlings in each treatment: 100 seedlings were used for morphological assessments (shoot length, root collar diameter, root dry weight, shoot dry weight, and total dry weight), and 25 seedlings were bulked for foliar nutrient analysis. Total foliar nitrogen was determined by the Kjeldahl method (Black 1965). Total phosphorous was determined colorimetrically using ammonium (meta) vanadate and the cations were analyzed by atomic absorption spectrophotometry after wet digestion of the foliar sample (Black 1965). The growing media were analyzed for percentage organic matter (Kalra and Maynard 1991: 27-30), percentage nitrogen using the Kjeldahl method (Black 1965), extractable phosphorous. Kalra and Maynard 1991: 74-77), and exchangeable K, Ca, and Mg using neutral normal ammonium acetate (Kalra and Maynard 1991: 84-85).

The trial was analyzed as a completely randomized design. Each seedling was treated as a replication.

Morphological data were analyzed by a one-way ANOVA after a logarithmic transformation (log x+1) to homogenize variances of shoot length, root dry weight, shoot dry weight, and total dry weight. Root collar diameters did not require transformation. All treatment means across both fertilization classes were compared by Tukey's studentized range test (HSD).

Results and Discussion

Fertilized seedlings grown in worm-casting-amended media were generally larger than non-fertilized seedlings grown in similar media. Fertilized seedlings grown in amended media had larger shoot lengths (figure 1), root collar diameters (figure 2), shoot dry weights (figure 3), and total dry weights (figure 5) than non-fertilized seedlings grown in similarly amended media. The only exception was treatment NFP_{10}, which had shoot lengths, root collar diameters, shoot dry weights, and total dry weights equal to the best of the fertilized treatments. Root dry weights (figure 4) of fertilized seedlings grown in amended media were as large as or larger than those of non-fertilized seedlings grown in sewage sludge castings but were often smaller than the root dry weights of non-fertilized seedlings grown in pig manure castings.

Seedlings that were both fertilized and grown in casting-amended media were not always the largest. The shoot lengths (figure 1) and shoot dry weights (figure 3) of fertilized seedlings grown in amended media were often smaller than the shoot lengths of

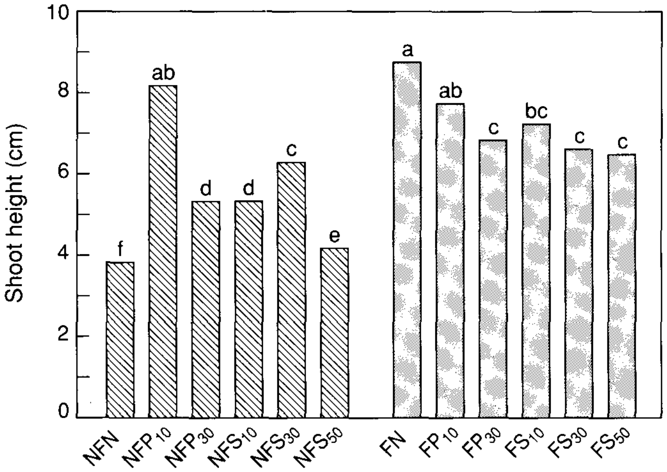

Figure 1—*Shoot heights of black spruce seedlings grown in a peat–vermiculite (3:1 by volume) nursery mix only or amended with worm castings. Bars with common letters are not significantly different* ($P \leq 0.05$).

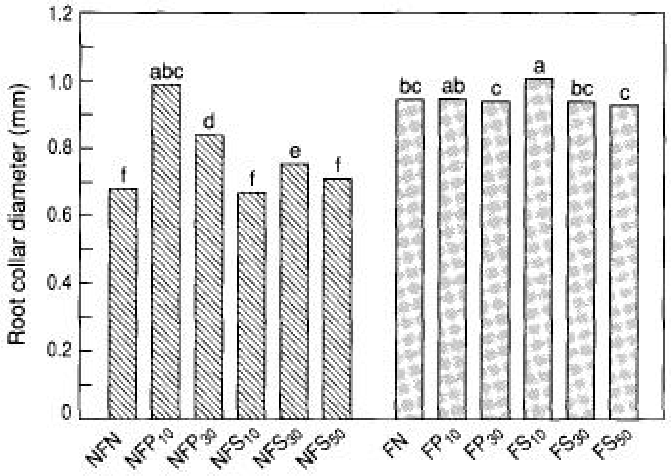

Figure 2—*Root collar diameters of black spruce seedlings grown in a peat-vermiculite (3:1 by volume) nursery mix only or amended with worm castings. Bars with common letters are not significantly different ($P \leq 0.05$).*

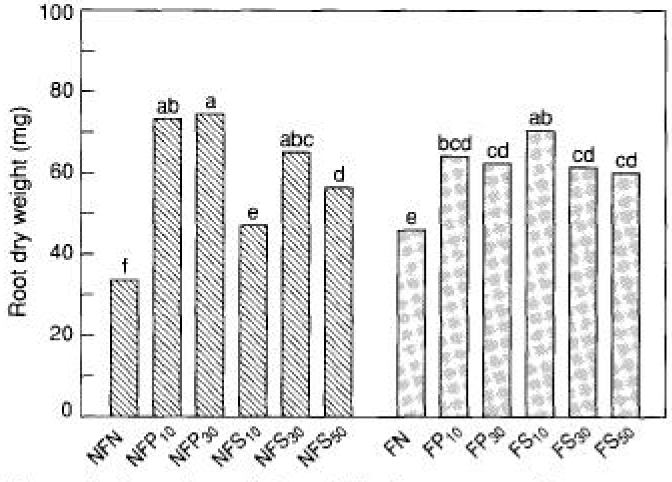

Figure 4—*Root dry weights of black spruce seedlings grown in a peat-vermiculite (3:1 by volume) nursery mix only or amended with worm castings. Bars with common letters are not significantly different ($P \leq 0.05$).*

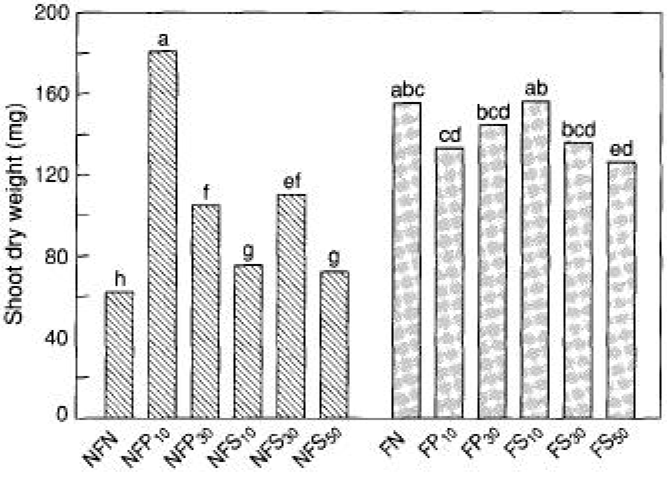

Figure 3—*Shoot dry weights of black spruce seedlings grown in a peat-vermiculite (3:1 by volume) nursery mix only or amended with worm castings. Bars with common letters are not significantly different ($P \leq 0.05$).*

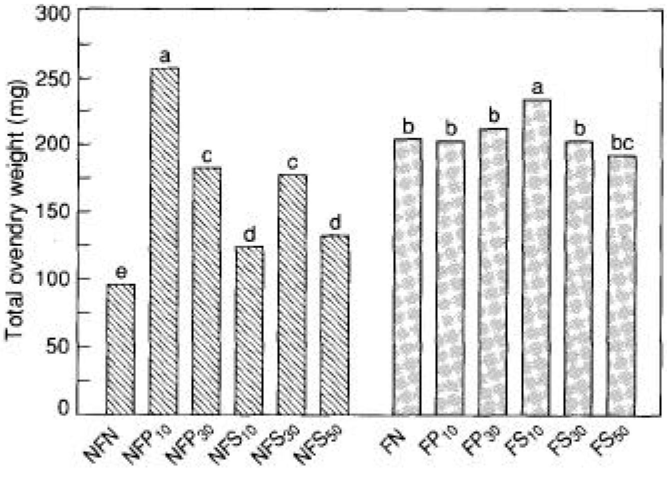

Figure 5—*Total dry weights of black spruce seedlings grown in a peat-vermiculite (3:1 by volume) nursery mix only or amended with worm castings. Bars with common letters are not significantly different ($P \leq 0.05$).*

seedlings grown in a non-amended peat-vermiculite media, treatment FN. But, the root collar diameters (figure 2), root dry weights (figure 4), and total dry weights (figure 5) of fertilized seedlings grown in amended media were as large as or larger than those of FN seedlings.

Non-fertilized seedlings grown in amended media generally did not grow as well as treatment FN, normal production seedlings; they had significantly smaller shoot lengths, root collar diameters, shoot dry weights, and total dry weights than normal production stock (figures 1-3, 5). The only exception was treatment NFP_{10}, which grew seedlings with similar shoot lengths, root collar diameters, and shoot dry weights, but significantly greater root dry weights and total dry weights than treatment FN (figures 1-5). The root dry weights (figure 4) of non-fertilized seedlings grown in amended media were equal to or significantly larger than FN seedlings.

Seedlings grown in non-fertilized pig manure castings were generally larger than seedlings grown in non-fertilized sewage sludge castings. The shoot lengths, root collar diameters, shoot dry weights, root dry weights, and total dry weights of non-fertilized seedlings grown in media amended with pig manure castings were generally as large as or significantly larger than non-fertilized seedlings grown in sewage sludge castings (figures 1-5). Fertilization reduced most of the differences in seedling growth between casting-amended media. The only exception was treatment FS_{10}, whose seedlings had shoot lengths, root collar diameters, shoot dry weights, root dry weights, and total dry weights as large as or significantly larger than fertilized seedlings grown in pig manure castings.

Increasing the percentage of castings in the media mix did not always increase seedling growth. Increasing the percentage of pig manure castings in a non-fertilized media mix reduced seedling shoot length, root collar diameter, shoot dry weight, and total dry weight (figures 1-3, 5), but did not appear to affect root dry weight (figure 4). For fertilized seedlings, increasing the percentage of pig manure castings in the media significantly decreased seedling shoot length and root collar diameter, but had no effect on shoot, root, or total dry weights (figures 1-5).

Similarly, increasing the percentage of sewage sludge castings in the media did not always increase seedling growth. Non-fertilized seedlings grown in media amended with 30% sewage sludge castings had significantly larger shoot lengths, root collar diameters, shoot, root, and total dry weights (figures 1-5) than non-fertilized seedlings grown in media amended with 10 or 50% sewage sludge castings. Within the fertilized treatments, the largest seedlings were grown in media amended with a lower percentage of sewage sludge castings. Fertilized seedlings grown in media amended with 10% sewage sludge castings had similar shoot lengths and shoot dry weights (figures 1 & 3), but had significantly larger root collar diameters, root, and total dry weights (figures 2, 4, & 5) than fertilized seedlings grown in media amended with 30 or 50% sewage sludge castings.

Analysis of the growing media (table 1) showed that the levels of N, P, and Ca were higher in casting-amended media than in the control (FN), but the levels of Mg were lower in casting-amended media than treatment FN. With the exceptions of NFS_{30} (Mg), NFS_{50} (N and Mg), and FS_{50} (Mg), levels of N, P, K, Ca, and Mg in the media generally increased with the proportion of castings in the mix (table 1). The levels of N, P, and K were generally higher, and Ca and Mg were generally lower in the fertilized treatments than the levels in the non-fertilized treatments similarly amended.

Levels of inorganic nutrients in the media alone could not explain the observed differences in seedling growth. For example, total seedling dry weight (figure 5) did not always increase with an increase in the level of inorganic nutrients. When the proportion of castings in the media increased from 10 to 30% in treatments NFP_{10} and NFP_{30}, total seedling dry weight decreased, even though the levels of N, P, K, Ca, and Mg in the media increased. There is a possibility that other substances may be present in worm castings. For example, enhanced root growth associated with the use of worm castings may be related to the presence of growth-promoting substances in castings (Grappelli *et al*. 1985).

Concentrations of foliar macroelements (table 2) were within an acceptable range for container grown seedlings (Landis 1985). Seedlings grown in casting-amended media had higher foliar concentrations of Ca than seedlings grown in non-amended media. Except for zinc, concentrations of foliar microelements (table 2) were within acceptable ranges for seedling growth (Stone 1968), although the concentrations of manganese were higher than normal Landis (1985). Foliar manganese concentrations declined in fertilized and non-fertilized seedlings grown in media containing a higher percentage of sewage sludge castings and in fertilized seedlings grown in a higher percentage of pig manure castings. Differences in foliar calcium or manganese did not appear to be related to differences in seedling growth.

In this trial, foliar zinc concentrations (240 to 300 ppm) were highest in seedlings grown in media amended with 10% pig manure and 10% sewage sludge castings and exceeded the upper critical tissue concentration of zinc (226 ppm) reported for Sitka spruce (Burton *et al*. 1983). Foliar zinc concentrations were also high in treatment NFP_{30}. Although no symptoms of toxicity were observed in this trial, seedling growth can be reduced by toxic concentrations of microelements, especially heavy metals. As foliar zinc concentrations declined when a higher percentage of castings was used, it is possible that the availability of zinc changed with the proportion of castings used in the media mix, perhaps due to differences in soil pH (Milner and Barker 1989). As heavy metals in sewage sludge are not always removed by composting (Coleman *et al*. 1987), caution should therefore be exercised in their use.

A potential advantage of a suitable amendment over a non-amended peat-vermiculite mix is that there would be no need to prepare and apply water

Table 2—*Foliar nutrient analyses of shoots of black spruce container seedlings grown in media amended with worm castings*

	Total	Percent inorganic nutrients							
Treatment	%N	P	K	Ca	Mg	Mn	Fe	Zn	Cu
NFN	2.05	.249	.846	.482	.146	.101	.0120	.0173	.00133
NFP$_{10}$	2.29	.283	.839	.499	.136	.108	.0118	.0242	.00098
NFP$_{30}$	2.26	.281	.726	.776	.165	.119	.0132	.0221	.00066
NFS$_{10}$	2.48	.353	1.135	.752	.180	.112	.0143	.0301	.00098
NFS$_{30}$	1.69	.316	.996	.705	.155	.015	.0120	.0148	.00138
NFS$_{50}$	2.04	.289	.773	.790	.151	.012	.0199	.0141	.00137
FN	2.86	.285	972	.410	.166	.050	.0100	.0134	.00122
FP$_{10}$	2.90	.261	1.111	.822	.205	.129	.0164	.0306	.00129
FP$_{30}$	2.31	.361	.896	.701	.145	.052	.0154	.0156	.00130
FS$_{10}$	2.26	.298	.947	.661	.177	.094	.0215	.0246	.00095
FS$_{30}$	2.25	.297	.831	.697	.153	.015	.0136	.0136	.00101
FS$_{50}$	2.32	.260	.850	.833	.154	.009	.0128	.0116	.00097

soluble fertilizers. However, a potential disadvantage is that there is a loss of ability to manage crop growth by decreasing fertilizer rates once a soil amendment has been made. To be a feasible alternative, worm-casting amendments must produce superior seedlings at comparable cost when compared to normal seedling production practices. The root growth simulating properties of worm-castings potentially may offer a means of producing superior seedlings. These results indicate that further work is needed to determine whether a beneficial worm-casting medium amendment exists for tree seedling production.

Summary

Trial results can be summarized as follows:

1. Non-fertilized seedlings grown in media amended with 10% pig manure castings (NFP$_{10}$) had the best growth of any treatment.
2. Except for treatment NFP$_{10}$, fertilized treatments grew larger seedlings than non-fertilized treatments.
3. Fertilization reduced differences in seedling growth between casting-amended and non amended treatments.
4. Within the fertilized treatments, media amended with 10% sewage sludge castings (FS$_{10}$) grew the largest seedlings.
5. All casting-amended treatments enhanced root growth.

Acknowledgments

The authors wish to thank Mr. R. Cameron (currently at Pineland Provincial Forest Nursery) and Mr. P. Schuessler (Swastika Tree Nursery) for their assistance in carrying out this trial.

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Comparison of Seeding Versus Planting Loblolly Pine in Rips

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Forest managers often rip planting sites in the Ouachita Mountains to ameliorate adverse soil conditions before planting. Direct seeding in spots was compared to normal planting of loblolly pine (Pinus taeda L.) seedlings on a site prepared by ripping. At the end of the first growing season, bareroot seedling survival averaged 47% and spot stocking was 15%. Analysis of variance indicated that shade created by woody competition and coarse-textured soil contributed to significantly higher stocking rates, emphasizing the importance of microsite conditions to the success of direct seeding. Tree Planters' Notes 43(2):48-51; 1992.

Forest managers have used direct seeding as a regeneration tool for many years. The development of reliable bird and rodent repellents for coating seeds stimulated considerable interest in direct seeding southern pines during the 1960's (Jones 1985). Although direct seeding fell out of favor with many forest managers during the late 1970's and early 1980's, the method has attracted some renewed interest among those seeking to develop alternative, low-cost regeneration methods appropriate for small ownerships (Hazel *et al.* 1989).

A wide range of direct-seeding technologies has evolved, including hand planting in spots, hand-held "cyclone" broadcast seeders, modified tractor-pulled agricultural row seeders, and aircraft-mounted units. The particular situation in which direct seeding is to be used will determine which technique to employ. For example, landowners with small properties find direct seeding in spots to be especially appealing because it is cheaper, faster, and easier than hand planting nursery-grown seedlings (Lohrey 1970). Spot seeding, because it permits better control of stocking and spacing, requires only a third to a half of the seed required for broadcast sowing (Campbell 1981). In some situations, direct seeding can be more attractive than natural seeding because the mature stand can be harvested without waiting for a good seed year to occur.

Regenerating pine in the Ouachita Mountains of Oklahoma is often a difficult task. Most soils have developed from metamorphosed sandstone, shale, and stony colluvium. Typically, soil profiles in the region consist of clayey topsoils over sandy subsoils with abundant rock, making these sites droughty and difficult to plant. Ripping is a popular practice when planting bareroot seedlings in the region (Wittwer *et al.* 1986). Ripping-loosening and mixing the soil to permit free drainage and aeration, thereby providing channels to collect surface runoff-can alleviate these adverse soil conditions (Wilson 1969). For example, subsoiling the graded spoil of a reclaimed coal mine in Illinois significantly reduced soil bulk density and improved seedling root and shoot growth (Philo *et al.* 1983). Ripping can also provide some control of competing hardwood sprouts by disturbing rootstocks. However, the exposure of bare mineral soil may provide a more favorable seedbed for annual weeds and grasses.

The purpose of this study was to compare the survival of planted bareroot seedlings versus direct seeded loblolly pine in rips. Furthermore, various factors of the microsite environment that seeds are placed in (degree of shading, presence and type of vegetative competition, soil texture, and color) that could affect seeding survival rates when sown in rips were studied. There are no previous reports on the possible benefits of ripping for direct-seeded loblolly pine.

Study Site

The study site is located in southeastern Latimer County, Oklahoma, near the western edge of the southern pines' natural range. The soil is classified in the Bengal-Denman association (Brinlee and Wilson 1981). While it is typically well-drained and deep, the soil is low in natural fertility and organic matter content. Permeability is slow and available water capacity is average. The surface layer is brown stony loam, overlying yellowish-red clay loam. The original stand, composed of mixed hardwood and short-leaf pine *(Pinus echinata* Mill.), was clear-cut during the winter of 1988-89. A considerable amount of hard wood slash and large stones were present on the site. The site was ripped to a depth of 38 to 45 cm (15 to 18 inches) during the fall of 1989.

Methods

During March of 1990, 1 + 0 bareroot loblolly pine seedlings were commercially hand planted in the rips, except for four replicate plots of 0.04 ha (0.10 acre) each reserved for direct-seeding, distributed over the 5.3-ha (13-acre) site. The four plots to be seeded each consisted of eight 20-m (66-foot) long, ripped rows spaced about 2.4 m (8 feet) apart. Within each row, nine planting spots were located, between 2.1 and 2.7 m (7 and 9 feet) apart, spaced to avoid rocks and other unfavorable areas. The planting spots were created by scratching loose a space of mineral soil 15 to 25 cm (6 to 10 inches) long. Twelve seeds were scattered over the scarified area and covered with the loosened soil. Hence, each replicated seeding plot contained 72 seed spots and 864 seeds, equivalent to 1,800 seed spots and 21,600 seeds/ha (8,640 seeds/acre).

The loblolly pine seed source was a single open pollinated family harvested in the Oklahoma Forestry Division seed orchard 5 years before the beginning of this study. It was sown in April 1990 after being stratified for approximately 2 months. A post-stratification germination test indicated that 95% of the seeds were viable. Because the seeds were covered during the planting process, little predation was anticipated and the seeds were not treated with repellants.

Each planting spot was subjectively classified according to four criteria:

1. Presence or absence of shade from adjacent stumps, logging slash, or vegetation
2. Presence and type of any competing vegetation
3. Soil texture
4. Soil color

Stocking of seeded spots and survival of planted seedlings was evaluated in May and August 1990 and January 1991. Bareroot seedling survival and total height in January 1991 were estimated from observations on 20 to 40 seedling planting-spots adjacent to each of the four seeded plots. Seedling planting-spots were located in the rips extending beyond the ends of the plots reserved for seeding. The presence of living, green cotyledons or primary and secondary needles, depending on the stage of development, was used as an indicator of germination and survival. The data were analyzed using Statistical Analysis System's GLM procedure because the sample sizes were unequal and the data did not fit into a balanced design (SAS Institute 1988).

Results and Discussion

Seeding and seedling survival exhibited a declining trend during the study period (table 1). Given the 95% germination rate determined in the laboratory, the maximum expected number of seedlings per spot was 11. Had all 11 seeds per spot germinated and survived, they would have produced 19,800 seedlings/ha (7,920 seedlings/acre). However, at the first tally in May, only 600 seedlings/ha (960 seedlings/acre) were present, representing 12.1 % of the viable seeds sown.

The 12.1 % "field" germination obtained in this study is better than the 3.7% observed in May following natural seed-fall of 1,124,300 short-leaf pine seeds/ha (455,000/acre) in East Texas (Ferguson 1958). However, in that study the seeds lay exposed to predation over winter, unless they were naturally covered by precipitation, leaf litter, or other natural events. The seeds in the present study had the advantage of being immediately covered during the seeding process. Loblolly pine seeds spot-seeded by pressing into bare mineral soil in mid-March exhibited maximum field germination of 17% when mulched with forest floor debris from the site in a Georgia study (Dougherty 1990). Seeds not covered with mulch failed to germinate. Survival at the end of the growing season (2.9%) is slightly less than that reported for a disking site preparation treatment in a natural short-leaf pine stand (Dale 1958). In that study, survival was 6.2% on bulldozed plots, 4.2%0 on disked plots, and 1.4% on untreated plots one year after seed-fall in Kentucky.

Despite the low overall seeding survival, in May, 51.5% of the seed spots (table 1), equivalent to 930/ hectare (370/acre), were stocked with at least one live seedling. However, by the following January, only

Table 1—*Survival and stocking of direct-seeded and bare-root seedling loblolly pine during the first growing season*

	Direct seeding		Bareroot seedlings
Measurement date	Survival[1] (%)	Stocking[2] (%)	survival (%)
May 1990	12.1	51.5	81.2
August 1990	3.6	18.0	61.7
January 1991	2.9	14.6	47.2

[1] Number of seeded trees as a percentage of all seeds planted.

[2] Number of stocked spots as a percentage of all planting spots.

about 15% of the spots remained stocked, equivalent to about 270/hectare (105/acre). The number of seedlings in the stocked spots ranged from 1 to 12. The stocking rate obtained at the end of the first growing season in. this study was comparable to the minimum reported in a North Carolina study (Hazel et al. 1989). They obtained milacre stocking (1 milacre = 4.05 m^2) ranging from 13.3 to 75.6% after one growing season on plots sown using hand-casting and broadcasting methods.

The initial drop in seeding survival and stocking may be attributed to the abnormal precipitation patterns observed from April through July. Unusually heavy rains during April and May washed a number of seeds more than a foot from their original location. In addition, approximately 4% of the seed spots were flooded during May. Other spots that failed to produce any germinates may have had seed either washed away or buried too deeply by water-borne sediment. During June, the site received less-than-normal rainfall. This low precipitation coincided with a 7 °C (13 °F) increase in the average monthly high temperature. Consequently, the remaining seedlings were subjected to unfavorable environmental conditions.

Some researchers have emphasized the importance of microsite conditions on seeding survival. Campbell (1964) argued that microsite conditions are perhaps more important than spot density when considering survival and height growth. More specifically, Dougherty (1990) demonstrated that mulching improved both seeding emergence and survival. In the present study, degree of shading from logging debris or vegetation, mostly hardwood sprout clumps, did not affect germination in May (table 2). However, at the end of the growing season a significantly higher proportion of shaded spots (especially those with woody vegetation nearby) were stocked than unshaded spots. Sufficient moisture in the uppermost soil layers is critical for germinating seeds and new seedlings. Shading may benefit the soil moisture regime for new seedlings by reducing direct evapotranspiration losses from the soil and seedlings. These hardwood sprouts will probably loose their beneficial influence and become true competitors as the pine seedlings develop and expand their rooting depth and volume. Significantly higher stocking levels were observed in August 1990 and January 1991 in spots with coarse-textured soil materials than in spots with medium or fine-textured soil. All microsite factors except soil color exhibited a significant effect on stocking for at least one of the observation dates.

Table 2—*The effect of shade, competition, soil texture, and soil color on the percent of spots stocked by direct seeding loblolly pine in Oklahoma*

Factor	Total spots 1990	% Stocking May 1990	August 1990	January 1991
Shade				
Shaded	42	64 a	31 a	26 a
Unshaded	246	49 a	16 b	13 b
Competition				
Woody	35	63 a	40 a	34 a
Herbaceous	212	47 a	15 b	11 b
None	41	63 a	17 b	15 b
Soil texture				
Coarse	54	59 a	30 a	26 a
Medium	130	55 a	21 ab	15 b
Fine	104	43 a	10 b	9 b
Soil color				
Red	83	52 a	24 a	22 a
Brown	80	51 a	18 a	14 a
Yellow	125	51 a	15 a	10 a

Means for a given factor and month followed by different letters differ significantly ($P < 0.05$).

In this study, as in other reports, planting bareroot seedlings resulted in higher stocking levels and is still recommended as the more reliable reforestation technique. At the end of the growing season, almost half the seedlings were still alive. This survival or stocking rate was over three times better than that for direct seeding. At the last measurement period, the bareroot seedlings had an average height of 25.4 cm (10.0 inches), with a standard deviation of 5.6 cm (2.2 inches). In contrast, direct-seeded trees had an average height of 9.6 cm (3.8 inches), with a standard deviation of 2.5 cm (1.0 inch). Direct seeding could be an attractive alternative to planting seedlings in some cases. Seeding in spots, while more labor intensive, might be especially suitable for small landowners from an economic viewpoint.

Full stocking is a high priority when attempting to regenerate a stand. There are two means of achieving full stocking by direct seeding: planting a sufficiently large number of seeds per spot to guarantee the survival of at least one live seedling per spot or planting a smaller number of seeds in enough closely spaced seed spots to insure full stocking. The results of this study indicate that specific characteristics of individual seed spots are very important in determining regeneration success. It appears that sowing a large number of seeds in a spot may not guarantee stocking if the microsite is unfavorable. Another approach may be to plant fewer seeds in more spots to increase the probability of encountering favorable microsites; however, this increases the labor required to seed a site.

The results of this study suggest that devoting attention to specific microsite conditions when selecting seed spots could improve seeding success. Shade created by logging slash or other vegetation was found to be beneficial in this 1-year study. However, the presence of vegetation may prove detrimental in subsequent years. Utilization of logging debris, stumps, rocks, and any available microtopographic features on the south and/or west side of spots selected for seeding to provide shade should be beneficial. In this study, coarse-textured soil materials, which are usually reddish and brown, were associated with improved seeding success. This guideline would need modification in other regions with different soils and parent materials of different geologic origin. The significance of soil texture for tree growth in various soil horizons is well recognized. However, for a germinating seed, only the material at and near the soil surface is of immediate importance. Taking some of these simple precautions to improve soil moisture and reduce soil surface temperatures near germinating seeds should improve the probability of successful regeneration with spot seeding techniques. More research is needed to develop seeding techniques that will result in stocking levels approaching reasonable success rates. The results of this study suggest some possible directions for future research.

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Seedcoat Removal Increases Speed and Completeness of Germination of Water Oak

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Germination speed and completeness of water oak (Quercus nigra L.) seeds were enhanced by the use of three seedcoat treatments: removal of the seedcoat, drilling a hole in one side of the seedcoat, and cracking the seedcoat. All treatments enhanced germination speed and completeness compared to the control, with removal of the seedcoat being the most effective. Application of this technique would be most useful when seeds are in short supply or when a research study requires a complete, uniform group of seedlings. Tree Planters' Notes 43(2):52-53; 1992.

Rapid and complete germination of seeds is usually a desirable objective in the production of tree seedlings. Seedlings thus produced are cultured more efficiently and production cost are reduced as a result.

There are numerous methods used to achieve this speed and completeness of germination. These include many stratification, scarification, and other preplanting techniques (Schopmeyer 1974). Depending on the species, one or more of these methods are used routinely by commercial tree nurseries. However, when small lots of seed for research purposes are being used, maximum germination and uniformity are highly desirable, especially with limited number of seed.

Seeds of species like the oak *(Quercus)* and hickory *(Carya)* groups have hard seedcoats that may slow hydration or prevent complete germination. Such seedcoats must be split by the developing embryo during germination. Removal of the seedcoat has been known to enhance germination in certain species (Schopmeyer 1974).

Water oak is a very common species across the Coastal Plain of the southern United States, and we need to know how to handle seed for nursery growing and in preliminary studies, removal of seedcoats greatly increased the speed of germination. This study was established to determine the effectiveness of several seedcoat treatments in increasing the speed and completeness of germination of water oak (*Q. nigra* L.).

Methods

Acorns were collected in the fall of 1990 from one parent tree. From a large group (stratified 90 days), 320 acorns were selected and assigned at random to one of four groups: untreated controls, seeds with a hole drilled in their coat, seeds that had their seedcoat cracked, and seeds with their seedcoat completely removed (80 acorns per treatment).

For drilling treatment, the end of a small laboratory knife was used to drill a hole (approximately 2 mm in diameter) without injuring the internal seed material. The hole was positioned in the top half of the seed. The cracking treatment was done by carefully tapping the acorn with a small hammer just hard enough to crack the seedcoat, but not enough to injure the living seed material. The seedcoat was removed by creating a crack in the shell and then carefully peeling the entire seedcoat from the seed.

Seeds were then soaked in tap water for 48 hours, drained, and assigned to planting containers. The containers, large Styroblocks, were filled with a 1:1:1 mixture of peat, vermiculite, and perlite. Seeds were planted 2.5 cm below the surface of the medium. The experimental design was a randomized complete block design with the treatments assigned randomly within four blocks. These were then placed in a greenhouse with night temperature between 18 to 20 °C and daytime temperature 26 to 30 °C. Each block was hand watered every 2 days and when germination started, seedlings were counted every 2 days.

Czabator's formula (1962), which quantifies germinative energy by combining speed and completeness of germination, was used for evaluation of the treatments. Combining both speed and completeness of germination into a composite score termed germinative value (GV) eliminates the need of subjective value judgement. The formula GV = MDG x PV was used where:

MDG (mean daily germination) = percentage of full seed at the end of test divided by the number of days to the end of the test.

PV (peak value) = mean daily germination of the most vigorous component of the seed lot, a mathematical expression of the break of the sigmoid curve representing a typical course of germination.

Czabator's formula was used to quantify the germinative value of the seed in the different treatments. (Analysis of variance was used to determine significance among treatments.) Percentage germination was also computed for comparison purposes, as the percentage of all filled seeds that germinated. Seeds that did not germinate after the experiment were dissected to ensure that they were filled.

Results and Discussion

There were highly significant differences among the treatments for peak value, mean daily germination, and germination value (table 1). Removal had the fastest and most complete germination. The seeds that had their coats removed began germinating by day 9 after planting and 89% had germinated by day 15. The second-best treatment was the drilled hole treatment, which first germinated on day 11 after planting and had 40% germination by day 15. The seeds with cracked seedcoats first germinated on day 13 after planting and had 35% germination by day 15. Untreated control seeds performed poorest, with no germination until day 15 after planting, when 6% germinated.

Removal of the seed coat also resulted in the greatest increase over the control in percentage germination (table 1). The drilling treatment ranked second, cracking coat treatment third, and the untreated control seed had the lowest percentage germination. Peak germination value, mean daily germination, and germinative value followed the same pattern (table 1). Removal of the seedcoat increased the germinative value by 11 times compared to untreated control seed.

Speed and completeness of germination for water oak seed can be maximized by the removal of the seedcoat. Removal of the seedcoat exposes the seed and bad seeds are easily discarded. The germination barriers the seedcoat presents are no longer in place and thus germination is faster and more complete.

Removal of the acorn's seedcoat is not a procedure for commercial production but can be utilized when limited numbers are involved, as would be with unique genotypes and small numbers of seed. The speed and uniformity of germination quickly produces a uniform group of seedlings, which is desirable for research work or when special seed lots must be maximized because of small numbers.

Table 1—*Peak values (PV), mean daily germination (MDG), germinative value (GV), and percentage germination for treated water oak seed*

Treatment	PV	MDG	GV	Germination (%)
Control	1.12 c	0.72 c	0.81 c	36
Cracked seedcoat	1.90 b	1.12 bc	2.19 bc	56
Hole in seedcoat	2.68 b	1.50 ab	4.02 b	75
Seedcoat removed	5.00 a	1.80 a	9.00 a	90

Values with the same letter are not significant ($P < 0.05$).

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