Improved Container Sowing With an Electronically Controlled Optical Seeder

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The efficiency and accuracy of an electronically controlled optical seeding machine was evaluated. This system required less than one-fourth of the labor needed to perform sowing with a vacuum seeder. Seed of coniferous forest species were sown with a high accuracy that filled all cells with undamaged seed. The seeder significantly increased the efficiency of sowing small-seeded species that are difficult to sow with a vacuum seeder. Efficient sowing of large pine and fir seed would require modification of the equipment. Tree Planters' Notes 42(3):4-8; 1991.

Sowing seed in container forest nurseries is highly labor intensive. Although the advent of vacuum equipment has increased the rate of placing seeds in cells (Hartman et al. 1990), considerable labor is still needed to ensure accurate sowing. At the University of Idaho Forest Research Nursery in Moscow, conifer sowing into Ray Leach® pine cells (200 cells per tray) has required 1 person to operate a Gleason® vacuum seeder and about 12 additional workers to add or withdraw seed to achieve the assigned number of seeds per cell, cover the sown trays with grit, and place the trays on benches.

An efficient vacuum seeder can sow large-seeded species with approaching 100%o accuracy when only 1 or 2 seeds per cell are required. However, vacuum seeders lose their accuracy when placing more than 2 seeds in a cell and when sowing smaller seed. Moreover, small seed such as those of spruce and larch tend to bury themselves into the sowing medium, making quick inspection for accuracy difficult. Accuracy also decreases when sowing lots with small amounts of seed if the operator cannot maintain a uniform layer of seed under the vacuum plate.

Some irregularly shaped seed pose special problems. Western redcedar is commonly hand sown (Macdonald 1986) because its small, light, flake-like seeds often form clumps of varying size on the vacuum plate or drum. The seeds are also difficult to separate by hand, so hand sowing is inexact, slow, and expensive.

A more accurate, automated sowing method would increase efficiency and reduce costs. This paper reports the accuracy and labor needs for sowing a conifer crop with an electronically controlled, optical seed-counting system mounted over a conveyor.

Materials and Methods

Machine description and operation. A greenhouse flat seeder (model 615-3), manufactured by the Old Mill Company® of Savage, Maryland, was installed in the University of Idaho Research Nursery in Moscow, Idaho, in March 1990. Utilizing the machine's flexibility to accommodate many tray types, we adjusted settings to sow trays of Ray Leach® pine cells comprising 20 rows of cells with 10 cells per row.

The seeder (figure 1) operates on 120 volt AC and 60 pounds per square inch compressed air to power the integrated seeding and tray-conveyor systems (Old Mill Company 1990). Seed poured into a vibrating bowl at the top of the machine move up a spiral path on the inside wall of the bowl, across a section of adjustable-width track, and into the top of a distribution tube. The distributor continuously dispenses seed into an upper bank of 10 storage tubes by optically counting 1 seed at a time (up to the preset number of seeds per cell) into a storage tube and then rotating to the next tube. When the upper bank has its seed allotment, a gate opens and seed drop into a lower bank of 10 tubes. A photoelectric control detects the leading edge of a tray and stops it when a row of cells is directly under the lower tubes. When this row is filled with seed a stepper motor advances the conveyor until the next row of cells is under the feeder tubes.

The rate at which trays are sown depends ultimately on the rate of seed supply. The machine operator selects the correct seed-size setting, adjusts the width of the seed delivery track in the feeder bowl to supply seed one at a time, assigns a target number of seeds to be sown per cell, and adjusts the

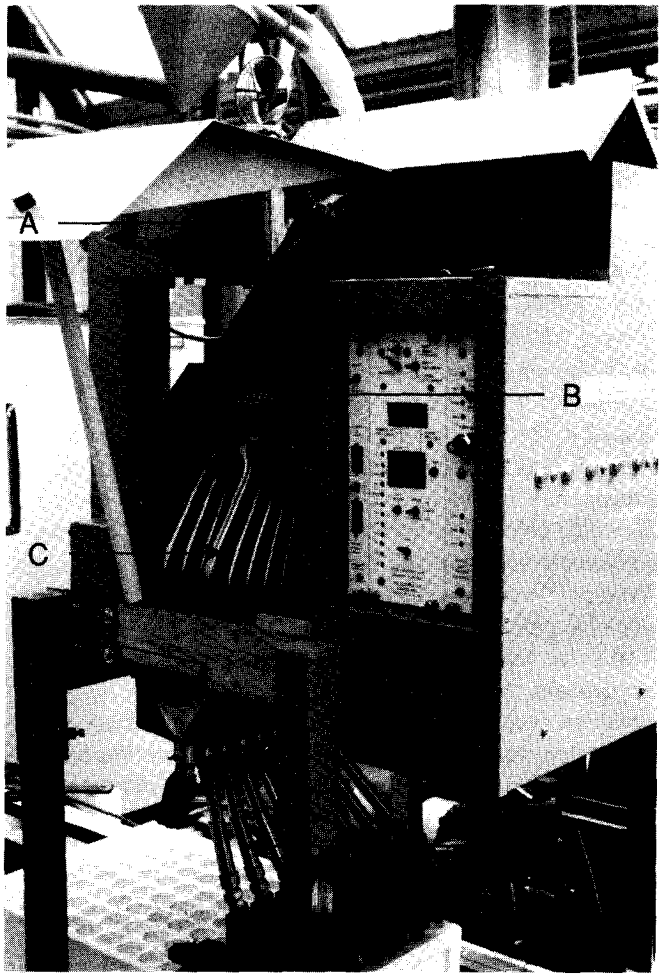

Figure 1—*Side view of the Oldmill® optical seeder and its conveyor. A = vibratory feeder bowl, B = rotary seed distribution tube, C = upper bank of storage tubes, D = lower storage bank.*

vibration frequency of the feeder bowl to control the rate of seed supply.

Materials. A total of 14 species of conifers were sown with the optical seeder at the Moscow nursery in 1990 and 1991. We present sowing data for western larch (*Larix occidentalis* Nutt.), grand fir (*Abies grandis* (Dougl.) Lindl.), Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Biessn.) Franco), western redcedar *(Thuja plicata* Donn.), Norway spruce (*Picea abies* (L.) Karst.), ponderosa pine (*Pinus ponderosa* Laws. var. *ponderosa*), and western white pine (*Pinus monticola* Dougl.).

Trials conducted. *Trial 1-seed distribution versus solving speed and seeds/cell*. We evaluated sowing accuracy by determining the seed distribution in the cells at various sowing speeds and a fixed target number of seeds per cell. The "sowing speed," defined as the sowing time in seconds per tray (s/tray), was varied by changing the frequency setting of the feeder bowl. Douglas-fir seed was sown at a target rate of 2 seed/cell into 3 groups of 32 trays of Ray Leach" pine cells (200 cells/tray) at sowing speeds of 88, 63, and 43 s/tray, respectively. The seeds in each cell of each timed tray were counted and their frequency distribution recorded as mean percentages.

The seed distributions of western larch, western redcedar, and Norway spruce were recorded at target rates of 2, 3, and 4 seeds/cell and a constant sowing speed of 88 s/tray.

Trial 2 sowing speed versus seeds/cell. The sowing speeds of ponderosa pine and western larch seed lots were determined as the target number of seeds/cell was increased from 1 to 4. The seed supply was held constant at a vibration setting of 420 as 10 trays were timed at random for each sowing target number.

Trial 3-sowing speed versus time of operation. This test timed the sowing of a tray every 15 min over a period of 6 h of continuous machine operation. Ponderosa pine was sown at a target of 3 seeds/cell and a seed supply setting of 420.

Results and Discussion

Machine operation. A total of 816,400 cells were sown in 4,082 trays during ten 8-h shifts from April 1 to April 9, 1991. Table 1 lists the number of cells sown at optimal operational machine settings with all the spring-sown species previously mentioned, except for grand fir. Since the optimal seed supply

Table 1—*Optimal vibration settings of the seed bowl and the resulting sowing speeds for various target numbers of seeds/cell and species sown under stable operating conditions*

Species	Seed feeder setting	Sow rate achieved (seed/cell)	Sowing speed (s/tray)	Cells sown/ 8 h
WL	520	3–4	70	82,000
DF	490	2–3	45	128,000
WR	442	4–5	64	90,000
NS	490	2–3	45	128,000
WP	540	2–3	60	96,000
PP	420	1–2	42	137,000
PP	420	3–4	120	48,000

WL = western larch, DF = Douglas-fir, WR = western redcedar, NS = Norway spruce, WP = western white pine, PP = ponderosa pine.

settings fell within a relatively narrow range (420 to 540), the operator must carefully adjust the sensitive control of seed-bowl vibrations for efficient sowing. The production of cells sown in an 8-h period generally decreased with an increase in the number of seed sown per cell. The optimal sowing speeds for ponderosa pine at 1 to 2 seed/cell and for Norway spruce and Douglas-fir at 2 to 3 seed/cell were comparable. However, production varied between some species at high sow rates per cell. For instance, the differences in sowing speeds between ponderosa pine and western larch of 3 to 4 seed/cell results in production of 48,000 and 82,000 cells, respectively.

A 2-person crew operated the seeder, inspected the sown trays for accuracy, covered them with grit, and moved the trays onto benches. Although a third person was required at sowing speeds faster than 45 s/tray, the overall labor requirement was less than one-fourth that used in vacuum sowing.

Trial 1-seed distribution versus sowing speed and seeds/cell. Douglas-fir seed, sown at the speed of 88 s/tray, resulted in 94.5% of the cells filled with the target number of 2 seed/cell (figure 2). In a major improvement over vacuum seeders, which often fail to pick up seed and thus leave blank cells, the electronic counter rarely produced an empty cavity. We found pitch fragments and detached wings in most of the blank cells. Seed purity may be a limiting factor in achieving further gains in accuracy with this equipment.

Increased sowing speed sacrificed accuracy. Since the seed counter tallied two or more seeds as one object at high rates of seed supply, the seed distributions were consistently skewed above the target setting. The accuracy in sowing Douglas-fir decreased from 94.5 to 52.5% as sowing speed increased (that is, the seeder spent less time per tray) from 88 to 43 s/tray (figure 2). Furthermore, a sowing speed of 43 s/tray filled 1.5% of the cells with 1 seed, 52.5% with 2 seed, 35% with 3 seed, 9.5% with 4 seed, and 1.5% with 5 seed to produce a target rate of 2.57 seed/cell.

A similar degree of accuracy was attained with the small-seeded species (table 2) sown at 88 s/tray, where 90 and 95%, respectively, of the western larch and Norway spruce were sown at the target rate of 2 seeds per cell. However, accuracy declined at 3 and 4 seed/cell targets with correspondingly wider frequencies of seed distributions. Vacuum plates commonly fail to lift all of the small angular seed of western larch. An increase in the efficiency of sowing western larch has value to nursery managers, because larch seed is expensive and often in short supply.

Western redcedar was also sown efficiently and accurately by the seeder. Hand sowing of 4 to 5 western redcedar seed/cell may take more than 3 min/tray. In contrast, the optical seeder sowed a target of 4.5 western redcedar seed/cell, at a sowing speed of 64 s/tray (table 1) and 75% accuracy (table 2).

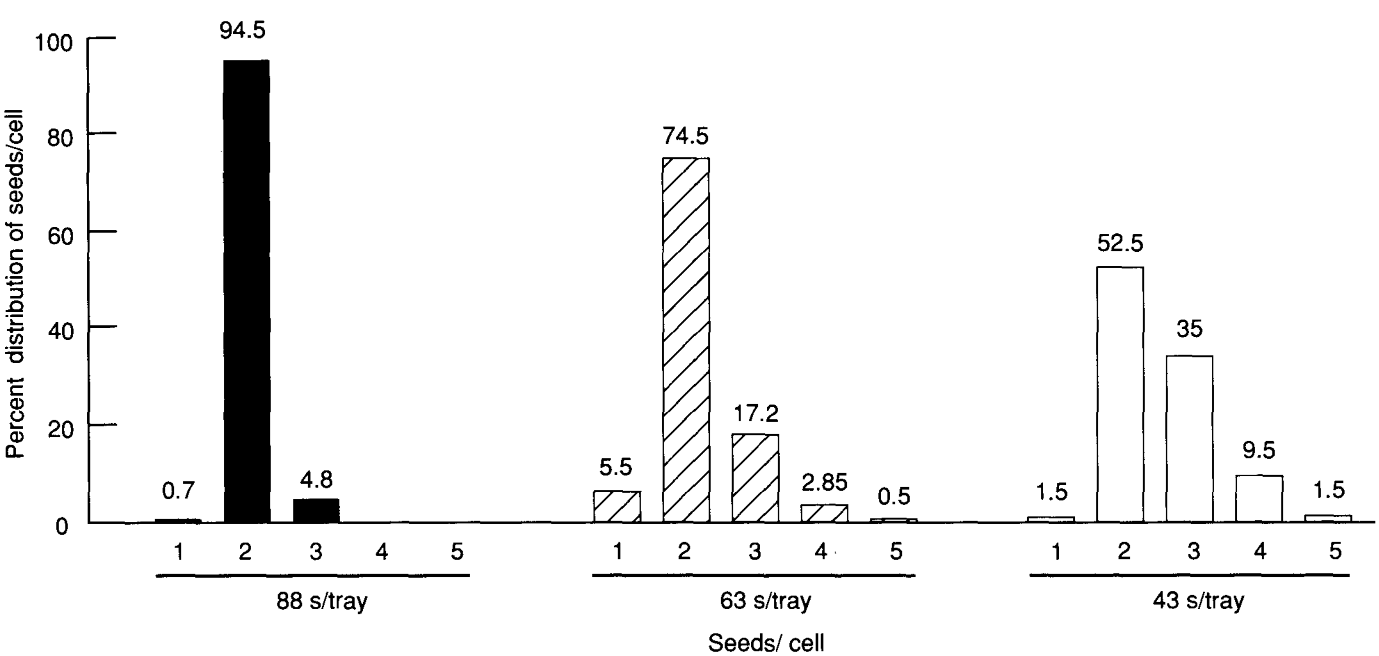

Figure 2—*Frequency distribution of seed/cell of Douglas-fir, at 3 sowing speeds (88, 63, and 43 s/tray), sown at a constant target rate of 2 seed/cell into 200-cell trays (trial 1).*

Table 2—*The frequency of seed distribution versus the target number of seeds/cell at a constant sowing speed of 88 s/tray (trial 1)*

Target (seed/cell)	Distribution of seeds/cell (%) 0	1	2	3	4	5	6	7
western larch								
2	0	3	90	6	1	0		
3	0	2	4	84	5	2	0	
4	0	0	2	6	76	12	2	0
western redcedar								
2	0	4	85	9	1	0		
3	0	2	6	80	11	1	0	
4	0	0	1	4	75	15	4	0
Norway spruce								
2	0	3	95	2	0			
3	0	0	3	90	6	0		
4	0	0	2	4	86	7	3	0

Trial 2-sowing speed versus seeds/cell. The target numbers of 1 and 4 ponderosa pine seeds/cell resulted in sowing speeds of 43 and 172 s/tray, with standard deviations of 8 and 7, respectively (figure 3). The machine placed an additional seed per cell across a tray in about 40 s as the sowing rate increased from 1 to 4 seeds/cell.

In contrast, despite the comparable sowing speeds of western larch and pine at 1 seed/cell, each additional larch seed per cell was placed in about 20 s. The pine was sown at a machine setting of "large seed" and the larch at a setting of "small seed." The electric eye of the seeder takes longer to make multiple counts of large seed per cell than small seed, because more small seed can be supplied to the distributor tube per unit time than large seed.

Trial 3--sowing speed versus time of operation. The sowing production slowly but steadily increased from 25 to 35 trays/h over a 6-h period from a cold start-up (a statistically significant correlation with a p-value <.0001). In addition, most malfunctions occurred in the first 2 h of a shift. We speculate that some physical factor such as moisture accumulated overnight or lower morning temperatures possibly influenced the mechanical and electronic systems, and that the heat generated by the operating equipment stabilized those systems over time.

Operational observations. The operator quickly and efficiently changed seed lots either by detaching, emptying, and replacing the feeder bowl or by feeding the remaining seed into the storage tubes and manually dropping them into a retrieval bowl on the conveyor. The system was rapidly cleaned with almost no seed loss.

Two types of malfunction occurred. Either several seed clogged the base of the distributor tube and the machine stopped sowing, or one or more of the gate shutters jammed leaving an equivalent number of blank rows in a tray. Most blockage could be attributed to supplying the machine with more seed than it could count. Once the operator had adjusted the seed bowl to deliver seed one at a time and found the maximum vibration rate setting controlling seed supply that did not overload the seed counting mechanism, blockages occurred only rarely, and the machine ran almost continuously for 16 h/day. These adjustments matched with a selected degree of accuracy defined an "optimal operational seed supply."

The machine treated the seed more gently than seeders using a vacuum plate. Operators frequently gently slide or bounce the vacuum plate to enhance seed pickup, a practice that can damage seed at the edges of the plate. We found no evidence of crushed seed, a common occurrence in the sowing of white pine and Douglas-fir with a vacuum plate.

Some large seed of ponderosa pine (up to 10 mm long and 6 mm wide) tended to clog the tapered, rectangular lower end of the distribution tube (inside dimensions 9.1 by 7.0 mm). However, all but the largest pine seed were sown successfully by slowing the seed supply. Grand fir seed has an angular form (Franklin 1974) and length up to 11 mm, exceeding

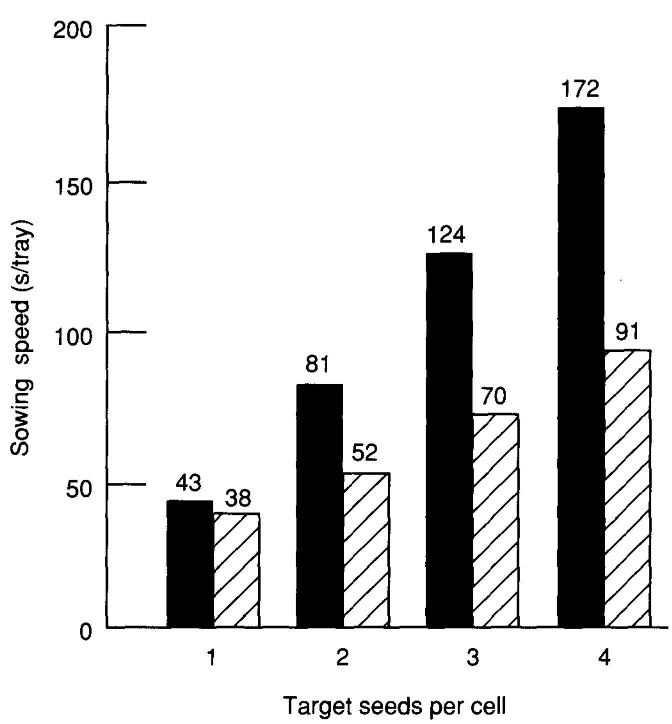

Figure 3—*Sowing speed (s/tray) versus the target number of seed/cell for ponderosa pine (solid bars) and western larch (hatched bars) at a constant seed-supply setting of the vibrating feeder bowl (trial 2).*

the inside diameter of the lower tubes. These qualities, combined with a high incidence of gum impurity, caused grand fir seeds to frequently block the distributor tube and both sets of gates. Grand fir was therefore hand sown.

Conclusions

The major advantages of the optical sowing system over vacuum sowing include lower labor requirements, a capacity for continuous machine operation, few blank cells, less physical damage to the seed, higher accuracy and faster sowing of small-seeded species, and more control in sowing fractional seed/ cell targets. The optical seeder could probably successfully sow all but the largest conifer seed in forest nurseries. Some equipment modifications will be necessary before grand fir and large-seeded ponderosa pine can be sown efficiently.

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Tree Planter's Notes, Volume 42, No. 3 (1991)

The Progeny Seeder

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A seeder to sow progeny test tree seeds in nurseries was developed by the USDA Forest Service's Missoula Technology and Development Center. The four-wheel, pedal-driven vehicle punches 96 dibble holes into the soil. A shutter-type tray then sows seeds simultaneously into each dibble hole. The seed trays are filled before field sowing. Because covering the seeds was not incorporated into the design, seeds must be covered with dirt or grit using a spreader or by hand. The seeder was developed as an alternative to the current labor-intensive plywood board sowing method. Tree Planters' Notes 42(3) :9-12; 1991.

As part of the Forest Service tree improvement program, Forest Service nurseries sow special high-value tree seed in test plots. The sowing specifications for these higher value seeds differ from normal sowing specifications. The progeny test seeder was developed to mechanize the sowing operation. Mechanizing sowing should reduce labor costs, reduce personnel injuries, and increase the rate of sowing.

The Missoula Technology and Development Center (MTDC) designed the progeny seeder (figure 1) for exact placement sowing of progeny test seeds in bareroot nursery beds. The sowing pattern was determined by Pacific Northwest Region personnel. The pattern can be modified to meet specific requirements. The seeder sows 96 seeds simultaneously in a pattern of 8 rows and 12 seeds in each row with rows spaced on 6-inch centers. The 12 seeds in each row are spaced in 3-inch centers. The development and growth characteristics of progeny test seedlings are closely monitored for tree improvement. Exact placement sowing is necessary to allow each seedling to display its individual genetic variations.

Progeny seeds have traditionally been sown by hand using a perforated 4- by 8-foot plywood board. A plywood sheet with holes drilled through it was placed atop the nursery bed. The progeny seeds were then dropped into the holes. The holes were filled with dirt to cover the seeds. The plywood board was then lifted and moved forward to the next planting location on the nursery bed. This method was tedious and labor intensive. A 5- or 6-member sowing team is required to bend and stoop over the nursery bed for long hours.

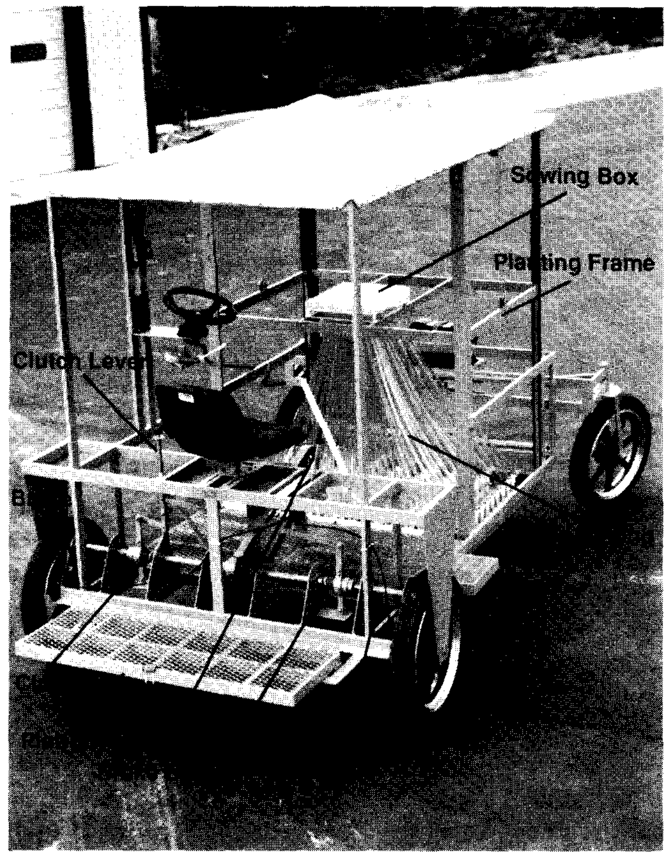

Figure 1—*Rear view of entire progeny seeder; note the operational features and the sowing box.*

The progeny seeder was developed as an alternative to this traditional method. It reduces the amount of bending and stooping required of the sowers and reduces the labor requirements by increasing sowing efficiency.

Description

The progeny seeder is a four-wheel, pedal-powered vehicle. It is 145 inches long, 90 inches tall, and 78 inches wide, and weighs about 1,200 pounds. The wheels are on 70-inch centers. The machine was designed for nursery beds that are 4 feet wide and have 18- to 24-inch paths.

The drive train consists of a chain drive input, a differential, two clutches, and a final chain drive to each of the rear wheels. A disk brake is attached to each rear wheel sprocket. The cable-operated brakes function as service brakes and parking brakes. A lever located to the right of the seat is used to operate the brakes.

Because of the seeder's extremely low gearing, it has a hitch and tow bar so that it can be towed between the field and the storage buildings. The pin connected tow bar is disconnected from the hitch and attached to the frame when the seeder is not being towed.

An operator must steer the seeder while the seeder is being towed. The final drives have been clutch-coupled to the differential. For the operator's safety during towing, the clutches must be disengaged before and during towing to keep the pedals from rotating. Maximum speed is 8 mph. A lever located to the left of the seat engages and disengages the clutches.

The steering system is adapted from a power boat steering system. A boat steering wheel, a single helm, and an 8-foot steering cable are used. The end of the steering cable is attached to the slider assembly located on the front of the seeder. Rotating the steering wheel controls the left-right movement of the slider assembly along two parallel stainless steel rods. A bar link connects each front wheel to the slider assembly. Thus, the left-right movement of the sliders along the two rods controls the steering of the front wheels.

A platform on the back of the seeder allows the sowers to cross the seed bed. The platform folds up to allow the sowers to cover the sown seeds with dirt as soon as possible after the seeds are sown.

The frame of the vehicle envelops a planting frame. The planter is raised and lowered within the frame of the seeder using the battery powered winch. Eight rows of planters are attached to the bottom of the planting frame. A sowing box is attached to the top of the planting frame. Clear vinyl tubing connects the planters to the sowing box.

The eight rows of planters are placed on 6-inch centers. Each row consists of a bar with 12 drop tubes and a bar with 12 carriage bolts. The drop tubes and carriage bolts are aligned and spaced on 3-inch centers along the row. The drop tubes control the placement of the seeds. The heads of the carriage bolts make the dibbles in the nursery bed. A lever located on the rear of the planting frame rotates the carriage bolts into and out of their functioning position.

The sowing box has eight rows of 12 holes drilled through its bottom surface. A clear vinyl tube connects each hole with its corresponding drop tube on the planters (figure 2). The sowing box will hold one seed tray.

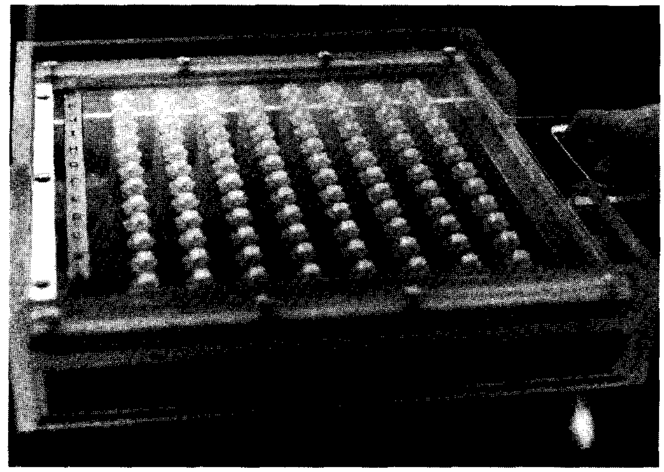

Figure 2—*Close-up of the seed box and seed tray; operator is about to release the seeds into the box.*

The shutter-type seed tray is a sandwich of three clear plastic plates. The top plate is a solid cover. The middle plate is the shutter for the bottom plate. The pattern of the holes drilled through the middle and bottom plates matches the pattern of the holes drilled through the bottom surface of the sowing box. The holes in the shutter plate and bottom plate are aligned and misaligned by sliding the shutter plate. When the seed tray is in the sowing box, the seeds are released by sliding the shutter to align the holes in the two plates and the sowing box (figure 3).

Operating Procedures

Sowing with the seeder is an indoor-outdoor process. The seed trays are filled inside the seed building. A vacuum pump with vacuum tweezers is provided to place the seeds in the seed trays. Several different sizes of tips are provided to accommodate various sizes of seeds. A seed tray is placed on the table with the bottom plate on the top. With the shutter plate positioned to align the holes of the shutter plate and bottom plates, the progeny seed are placed in the holes. The seeds are captured between the cover and bottom plates by sliding the shutter to misalign the holes of the shutter and bottom plates. After all the seed trays are filled, they are transported to the field for sowing. Wooden tote boxes have been designed for transporting the seed trays.

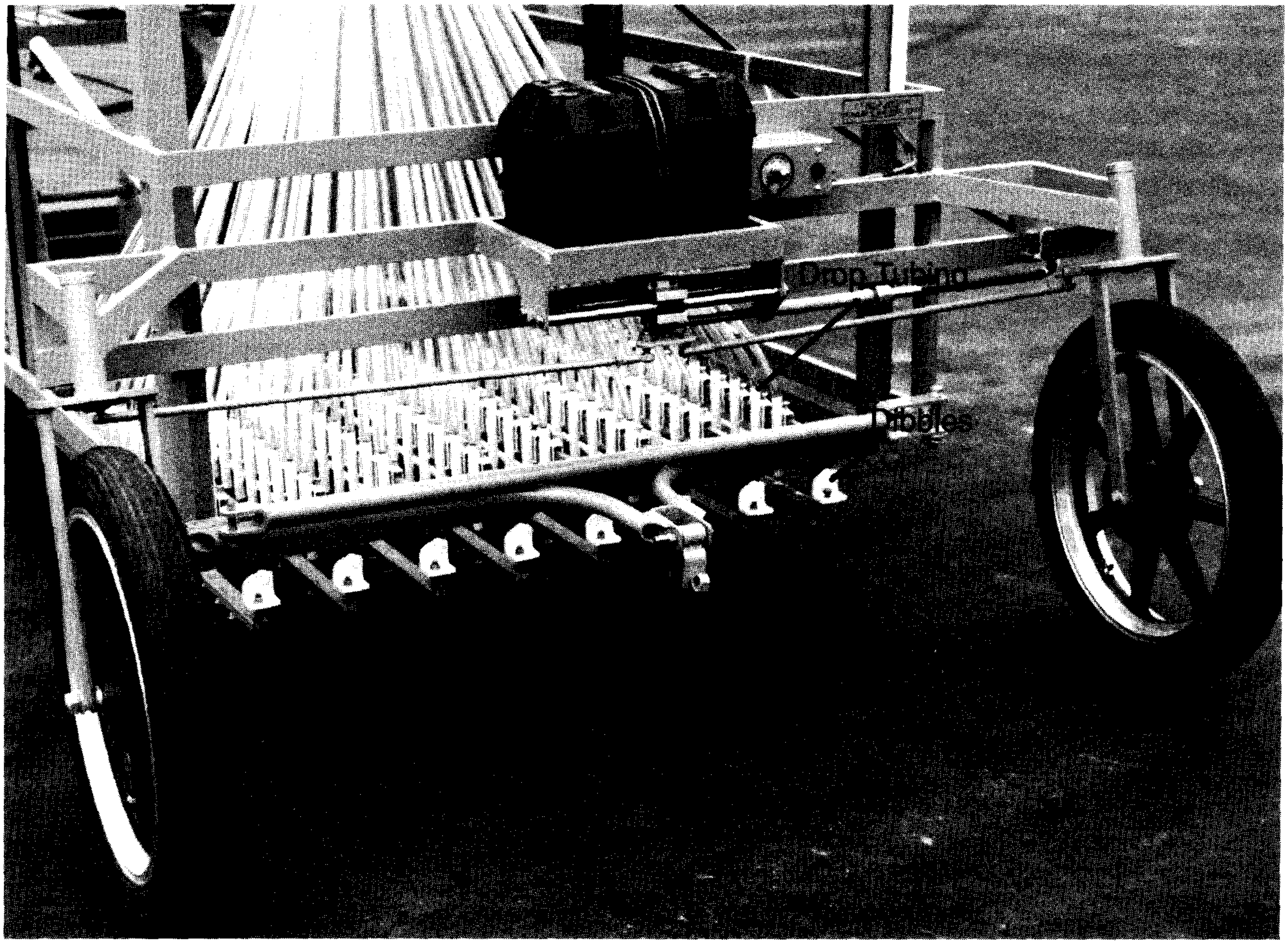

Figure 3—*Close-up of the tubing and the dibbles.*

After towing the seeder to the field, the operator provides the pedal power to position the progeny seeder along the nursery bed. The carriage bolts are placed in the functioning, or straight down, position. The electric winch is used to lower the planting frame until the bolt heads make dibbles in the nursery bed. After raising the planting frame slightly, the carriage bolts are rotated 90° to a nonfunctioning position. The planting frame is lowered to position the bottoms of the drop tubes just above the nursery bed. The seeder is now ready for sowing. A pre-filled tray is placed inside the sowing box. Sliding the shutter plate aligns the holes of the shutter plate, bottom plate, and sowing box to release the seeds (figure 3). The vinyl tubing guides the falling seeds into the dibbles. The winch is used to raise the planting frame slightly. The operator pedals the seeder forward to the next planting spot. An assistant operator covers the sown seeds with dirt or grit.

The progeny seeder was designed to be operated by a 3 or 4-person crew. One field person will operate the seeder; a second will cover the seeds and assist the operator. A third person, located in the seed building, will pre-fill the trays. A fourth person will transport trays to and from the field and provide assistance in the field or in the seed building as required.

Testing

Missoula Technology Design Center has fabricated two progeny seeders. The first one was fabricated in the fall of 1988 and was field tested at the USDA Forest Service's Wind River Nursery in Carson, Washington. It had a shutter box mounted atop the planting frame. The shutter box was filled with seeds in the field just prior to sowing. The same 4-person crew used the seeder for over a month and offered some suggestions for improvements. MTDC modified the first seeder and incorporated those modifications into the design of the second progeny seeder, which was fabricated in the spring of 1991. Three major modifications resulted from the Wind River field test.

1. The shutter box atop the planting frame was replaced with a sowing box to make the field sowing more efficient. An assistant operator covers the seeds when the progeny seeder is moved forward to the next sowing site along the nursery bed. It is faster to place a pre-filled seed tray into the sowing box than to fill the shutter box. Faster sowing allows the assistant operator to cover the seeds sooner. This minimizes the chance of seeds being displaced by the wind.
2. The planter rows on the original seeder were rigidly attached to the planting frame. A slightly uneven nursery bed would cause some dibble holes to be deeper than others or some dibble holes to be missing. Each planter row was modified with springs. The independent suspension of each row results in more uniformly sized dibbles.
3. As a safety measure, clutch couplings were added to the final drive of each of the rear wheels. This allows the progeny seeder to be towed without the pedals rotating. The ergonomics of the new seeder have been improved. The position of the pedals in relation to the seat are more compatible. The steering wheel was relocated from the back of the planting frame to the side of the vehicle.

The modified seeder was retested at Wind River Nursery during the 1991 spring sowing season. The redesigned seeder was also field tested this spring at the W. W. Ashe Nursery in Brooklyn, Mississippi, and at Bend Pine Nursery in Bend, Oregon. The results of these tests will be published after their evaluation.

From the preliminary testing of the original seeder, the sowing rate using the improved seeder should be slightly faster than the sowing rate using the plywood board. The number of workers necessary for sowing progeny seed has been reduced and since the amount of stooping is reduced, the stress on those workers has been reduced as well.

Information and drawings (ask for plan #858) are available upon request from:

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Missoula, MT 59801
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Economics of Mechanical Bulk Lifting at an Ontario Bareroot Tree Nursery

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Mechanical bulk lifting at the Thunder Bay Forest Tree Nursery in 1990 was a cost-effective alternative to manual lifting, sorting, and packaging black spruce (Picea mariana (Mill.) B.S.P.) seedlings. The mechanical bulk lift produced cost savings of approximately $15.38 per thousand (in Canadian dollars), representing a savings of approximately 29% relative to conventional lifting costs. The capital cost of the harvester was not included in the cost analysis. Nursery cultural practices, procedures for handling cull seedlings, and approach to handling seedlings at the planting site may have to be modified to accommodate mechanical bulk harvesting. Tree Planters' Notes 42(3):13-15; 1991.

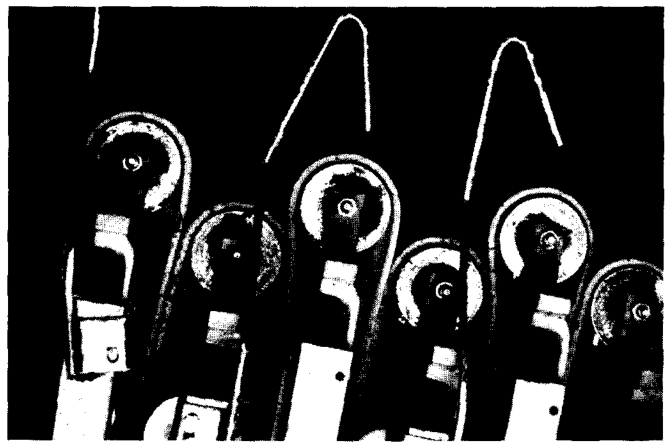
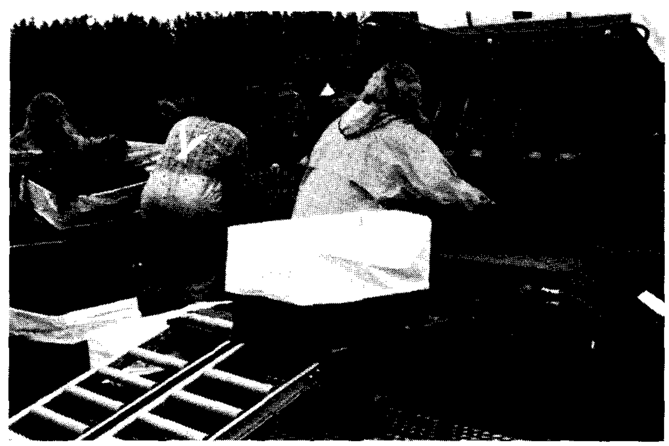


Figure 1—*Hovey eight-row mechanical belt seedling harvester in use at the Thunder Bay Forest Nursery in the fall of 1990. Note the counter-rotating belts on the lifting heads (**top**) and the positioning of the lifting crew (**bottom**).*



Bulk lifting refers to harvesting seedlings or transplants from nursery beds and packaging them directly into containers for shipment to the planting site without sorting, culling, counting, or bundling. This system reduces both the number of personnel required and the amount of seedling handling, which in turn reduces the risk of seedling damage (Trewin 1976) and lifting costs at the nursery.

In a conventional seedling harvest at an Ontario bareroot tree nursery, seedlings are first undercut by an Egedal lifting blade. Workers follow the machine, cull inferior seedlings, and bundle shippable seedlings in groups of 10 or 25. The bundles of seedlings are packaged into containers and placed in cold or frozen storage until they are shipped to the field for planting. This conventional lifting procedure is labor intensive, often involving over 200 workers, and has a high variable cost but low capital cost. Daily production levels at the Thunder Bay Forest Nursery during the 1990 spring and fall conventional lifts averaged 550,000 and 767,000 seedlings, which translates to 735 and 788 seedlings per worker per hour.

In mechanical bulk lifting, the counter-rotating lifting heads (figure 1) grip the seedlings near the root collar and remove them from the ground. The seedlings are separated and soil is removed from the roots by machine action. The seedlings are manually removed from the belt and packed in polyethylene-lined boxes, which are later sealed and transported to the cooler. This process requires approximately 8 to 12 workers, resulting in lower variable costs. Bulk harvesting at another Ontario nursery lifted an average of 180,000 seedlings during a 7.67-h day by a crew of 10 (Cameron 1988). This is equivalent to 2,347 seedlings/worker/h.

This note summarizes the economic analysis of bulk lifting during the first operational trial of the mechanical bulk lifter at the Thunder Bay Forest

Nursery. Full details of the trial are described elsewhere (Wiensczyk 1991).

Materials and Methods

Mechanical bulk lifting at the Thunder Bay Forest Nursery was conducted on black spruce (*Picea mariana* (Mill.) B.S.P.) techniculture (Klappratt 1990) transplant beds during the 1990 spring and fall seedling lifts using a Hovey 8-row mechanical belt seedling harvester. Techniculture transplants are produced in 5.7 cm^3 peat and polymer plugs and tend to produce uniform seedlings with compact root systems after transplanting into nursery beds. A total of 13,000 transplants were mechanically bulk-lifted in the spring and 177,648 in the fall using the bulk lifting approach.

Lift productivity for the mechanical bulk lift was determined by counting the number of full boxes of transplants harvested over known lengths of nursery bed and time periods. An estimate of the number of trees that could have been lifted during the spring trial, in the absence of mechanical breakdowns, was based on the total length of time the machine was in operation and the number of trees lifted during measured five minute intervals (table 1).

Table 1—*Cost comparison of 1990 spring and fall conventional seedling harvests and mechanical bulk lifting at the Thunder Bay Forest Nursery*

	Total no. seedlings	Total cost to Nursery	Cost/1,000 seedlings
Conventional lifting			
Spring	8,156,119	$431,481	$ 52.91
Fall	7,310,760	$384,442	$ 52.59
Bulk lifting			
Spring	13,000	$ 5,402	$415.55
Spring*	144,000	$ 6,318	$ 43.88
Fall	177,648	$ 6,611	$ 37.21

*Estimate based on potential productivity without equipment breakdowns; costs are given in Canadian dollars.

The numbers of contract and nursery employees involved in the bulk lift were recorded as were the numbers and types of equipment used.

Lift productivity for the conventional lift was determined by counting the number of boxes of seedlings as they were placed into cold storage at the nursery. The total numbers of lifters, packers, and support staff as well as the total time worked were recorded.

Boxes of bulk-lifted seedlings were selected and marked at random for seedling counts and cull assessment. Harvested trees were assessed for cull using the same Ontario standards as used for the conventional lift. Trees were considered cull if height was less than 15 cm, root collar diameter was less than 2.6 mm, roots were malformed, or the seedlings had been physically damaged. Boxes of seedlings were weighed before they were assessed. The empty box was also weighed to determine the amount of soil remaining in the boxes after trees were removed.

Results

The cost to the nursery of the spring and fall conventional and mechanical bulk lifts are summarized in table 1. The cost per thousand was similar for the spring and fall conventional lifts with a difference of $0.32/1,000 (Canadian dollars).

Only 13,000 of the intended 100,000 trees were lifted in the spring because of mechanical problems with the harvester. Estimates of productivity, based on the number of seedlings lifted during measured 5-min operating intervals, showed that 144,000 trees could have been lifted in the same time period had no breakdowns occurred. These estimates were used primarily to corroborate the results of the fall lift.

During the fall bulk lift, the mechanical harvester operated for a total of 11.75 h. In the 11.75 h that the harvester was in operation, 931 boxes containing an estimated 177V648 trees were harvested (table 1). An additional 5.2 h were lost to mechanical breakdowns (29.9% down time) and 0.45 h were lost to coffee breaks. This equates to approximately 1,000 seedlings/worker/h.

Two assumptions were made in estimating the cost of the bulk lift: that the mechanical harvest was a separate operation and there would be no crossover of employees or equipment to the manual lift should a mechanical breakdown occur, and that employees would be paid during equipment down time. The total payable time for the fall bulk lift was therefore 17.4 h. This figure was used in the cost analysis.

The cost saving for the fall bulk lift was estimated to be $15.38/1,000 seedlings, which represents 29% of the cost of the fall conventional lift. Assuming the nursery lifted 50% of its stock production target (7.5 million seedlings) using the mechanical bulk harvester, an annual cost savings of almost $119,000 could be attained. Note that the capital cost of the harvester (approx. $65,000) was not included in this cost analysis. The capital cost of the mechanical harvester was not included in the total costs because it will vary substantially with the number of machines purchased, the financing arrangements, and the extent of modification required to get the machines operational. In addition, it is not known how long the machines will last under normal use before replacement or a major refit is necessary. Capital costs were also not included for the conventional lift.

Nursery soil was not adequately removed from the roots of the mechanically bulk-lifted seedlings prior to packaging. The boxes weighed significantly more than boxes of conventionally lifted stock. The average weights of mechanically bulk-lifted seedlings from two compartments were 27 kg and 36 kg, compared to 19 kg average box weight from a stock lot harvested by conventional lifting despite a greater number of trees per box from the conventional lift. Excessive soil means fewer seedlings per box and increased shipping costs. Heavier box weights may also increase the risk of work-related back injuries, risk of boxes being crushed while in transport, and increased incidence of disease outbreak on packaged seedlings. In addition, it was estimated that approximately 14 tons of fertile nursery topsoil were shipped to the field in the boxes of bulk-lifted stock. Modifications to the soil removal system on the mechanical bulk harvester are planned to help alleviate this problem.

Discussion

One of the drawbacks of bulk harvesting is that harvest and shipping estimates are only as accurate as the nursery bed inventory, which is usually determined within ± 5 percent. In addition, the variability in the number of seedlings per box can be expected to vary with the stock lot, the average size of the seedlings, and the size variability of the trees harvested. Area-based planting (Guthrie 1990) may be necessary to enable the field to accommodate bulk-lifted stock and the inherent variability in shipping inventory (Wiensczyk 1991).

Based on the productivity figures for the fall bulk lift, up to 6 additional mechanical harvesters and 84 workers would be needed to harvest the 7 million seedlings lifted in the same time period as the conventional fall harvest, assuming no major mechanical breakdowns. It is fair to assume that productivity will increase as workers become more familiar with the equipment, or as the mechanical bulk-lifting process is streamlined as a result of increased experience with the process.

The cost of lifting seedlings using the mechanical harvester is dependent on machine efficiency. Several factors, including seedling density in the nursery beds, time of day, and mechanical breakdowns, were all found to affect harvester productivity (Wiensczyk 1991). Productivity increased as the day progressed.

The techniculture transplant system is particularly well suited to mechanical bulk lifting because the uniform seedlings with a compact root system minimize the need for culling or root pruning. Cull levels of the mechanically bulk-lifted stock averaged 8%. Less than one-third of the cull was the result of physical abnormalities or damage attributable to the mechanical bulk harvester. Boxes of conventionally lifted stock may contain up to approximately 5% cull seedlings, even after sorting and grading. Cull levels of the bulk-lifted stock could be significantly reduced if undersized seedlings were removed during hand weeding operations. Alternatively, cull levels and variation in the number of trees per box would be expected to be higher if lifted from less uniform seedling or transplant beds. High cull levels (>10%) may render mechanical bulk lifting impractical.

Conclusions

From this trial the following conclusions can be made:

- Mechanical bulk lifting provides a significant cost savings over conventional harvesting (capital costs not included).
- Mechanical bulk lifting requires uniform stock with low cull levels to be effective.
- Operational shipping and planting procedures that require precise estimates of the number of trees per container may need to be modified to accommodate bulk-lifted stock.

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Tree Planter's Notes, Volume 42, No. 3 (1991)

New Style Acorn Seeder

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A simple mechanical acorn seeder developed by the USDA Forest Service Toumey Nursery is described. A Wind River Seeder Frame was modified by inserting holes in a rotating drum to allow acorns to pass through the drum. The seeder sows 8 acorns per foot of nursery bed, and its use can produce substantial savings in time and money. Drawings are available upon request from the senior author. Tree Planters' Notes 42(3):16-17; 1991.

The James W. Tourney Nursery is a USDA Forest Service tree nursery located in the western upper peninsula of Michigan. Established at Watersmeet, Michigan, in 1935, the nursery currently produces approximately 4 million seedlings annually for the national forests in the Lake States.

Over the last few years regeneration of oak stands has received increasing emphasis. This has resulted in increased orders for quality oak planting stock. Research into nursery cultural regimes and their effects on field survival of oak has shown that seedbed density is a critical factor in seedling growth and survival. Currently Tourney Nursery is growing oak at a target density of 6 seedlings per square foot. At this low density, in-row spacing is critical. Too-wide spacing or missed spots will increase the per seedling cost of bed treatments. Too many seedlings per linear foot can reduce seedling growth and survival.

For lack of a better method to achieve consistent acorn spacing during sowing, Tourney Nursery was sowing acorns by hand. We had tried mechanical acorn planters but had not found any that produced the desired precision in spacing.

Roy Kangas, of the Forestry Sciences Laboratory in Houghton, Michigan, through a cooperative agreement with Jud Isebrands and the USDA Forestry Sciences Laboratory in Rhinelander, Wisconsin, had identified the need for a mechanical acorn planter. Roy came up with the idea of a rotating drum and spent part of the winter working on the concept. When Roy presented his concept to the personnel at Tourney Nursery last summer, they were intrigued and jumped at the chance to help him with his project.

The first step in making an acorn planter was to find a way to get acorns out of a container one at a time. First Roy tried moving an outer plate around a horizontal drum with holes in the bottom. The acorns would bridge or come through several at a time. Then he left the outer plate stationary and started turning the drum. With the hole on the bottom, this still did not give consistent results. Roy then moved the outer plate hole to the 9 o'clock position and added a sheet metal pickup on the inside of the drum to carry a single acorn above the mass of acorns. The angled pickup, combined with centrifugal force, allowed the acorn to exit when the outer plate ended. This method produced consistent, satisfactory results; thus the rotating drum concept was adopted.

The prototype for Tourney Nursery was built on an old Wind River seeder frame with the adjustable cone gearbox (figure 1). The drum that was selected is a 26-inch-diameter fiberglass drum. It was cut to 50 inches wide, with five rows of holes; thus five rows can be planted at one time. The $1^1/_8$-inch holes

Figure 1—*Ground-driven seeder sowing 5 rows of acorns.*

were placed 3.1 inches apart around the drum, resulting in 26 holes around the circumference for each row. Therefore, a five-row unit plants 130 acorns with one revolution of the drum. Drum speed of 27 revolutions per minute equaled 1 mile per hour, sowing 8 nuts per foot in each of 5 rows. The drum was driven from a bed roller on the front of the drill. The speed of the drum and thus the number of acorns planted per row foot could be adjusted through the adjustable cone gear box. This gear box was later abandoned in favor of a more direct drive type of system where the drum speed could be adjusted by changing gears.

The adjustable outer plate was adjusted so the acorns would exit into the tubes at the 9:30 o'clock position. Formed sheet metal strips were used for the pickup apparatus rather than individual pickups for each hole. Three-inch flexible tubes guide the acorns to the floating furrow openers. The furrow openers are suspended from cables so they can move up if obstacles are encountered. By adjusting the length of the cable, the depth is adjusted.

The machine was first used the fall of last year to sow northern red oak acorns at Tourney Nursery. The machine performed excellently. Acorn density and placement was comparable to hand sown beds. Acorns spacing was very consistent, and numbers per row foot usually varied by less than one acorn. The nursery planted approximately 100 bushels of acorns in the first afternoon.

Substantial cost savings were realized in the sowing operationals. Hand sowing requires approximately 3 person-hours per bushel, and machine planting reduced this to less than .4 person-hours per bushel. Further savings may be realized, since consistent spacing results in more uniform and higher quality seedlings thus reducing the cull rate at shipping time.

Future refinements are expected to include a hopper system to feed the drum so that more acorns can be carried on the machine, a dirt screen on the bottom of the outer plate to remove dirt, and a different type of furrow closer. This acorn planter could easily be adapted to plant ten rows in a 4-foot-wide bed or plant other large seeded species such as plum, cherry, or walnut. The machine also has the potential to tumble pregerminated acorns to clip the radicles before planting, thus increasing the number of large lateral roots on seedlings (Ponder 1990).

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Phenotypic Variation in Cone and Seed Characteristics of Tamarack in Northwestern Ontario

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Variations in cone size and morphology, number of seed per cone, percentage filled seed, percentage insect-damaged seed, and seed dimensions were evaluated in individual tree samples collected in 1984 from nine regions of northwestern Ontario. Nested analyses of variance revealed no major provenance differences in cone or seed morphology, but there was substantial variance among stands within provenances and trees within stands. Percentage of filled seeds was lower in northern (51 to 56°) than in southern (46 to 49°) populations, and samples from Fort Severn on Hudson's Bay, the most northerly source, contained less than 1 % filled seed. Within population variance in characters related to seed productivity (for example, number of seed per cone) was large enough to suggest that selection for these characters may be effective. Tree Planters' Notes *42(3):18-22; 1991.*

One of the often noted barriers to the expanded use of tamarack *(Larix laricina* (Du Roi) K. Koch) in boreal forestry is the species' sporadic cone crops and generally poor seed set under natural conditions (Armson 1983). Because of this, most of the currently limited production of planting stock relies on relatively expensive vegetative propagation. Improvement of seed quality and production under orchard conditions, via either genetic or environmental manipulation, would allow a broader approach to stock production. There are, however, few published data on seed and cone characteristics upon which one might base a strategy for improving production. Therefore, during the course of collecting material for a genetic study of tamarack in northwestern Ontario we formally evaluated phenotypic variation of some seed and cone characteristics in 1984, a year when cone production was relatively high in eastern and central Canada.

Methods

In August and September 1984, before seed dispersal began, cones were collected at nine locations (table 1). The two sampled stands selected in each

Table 1—*Provenance means and range of tree means for cone and seed production characteristics of tamarack in northwestern Ontario*

	Provenance	Lat. (deg. N)	Long. (deg. W)	Cone length (mm)	Cone width (mm)	Number scales per cone	Cone scales per mm	Number seed per cone	Percent seed filled	Percent seed insect damaged
01	North Bay	46°	80°	10	7	14	1.36	20	9	20
		60′	52′	(9–12)	(6–9)	(9–17)	(.92–1.70)	(16–24)	(1–26)	(0–82)
02	Sault Ste. Marie	46°	83°	10	6	11	1.18	16	2	50
		80′	70′	(8–11)	(6–7)	(9–14)	(1.01–1.32)	(9–24)	(0–7)	(9–80)
05	Thunder Bay	48°	89°	11	8	14	1.21	27	13	45
		40′	32′	(8–12)	(7–8)	(12–17)	(1.03–1.41)	(21–31)	(3–38)	(1–75)
06	Ft. Frances	48°	94°	12	8	16	1.4	23	25	21
		70′	15′	(9–15)	(6–9)	(9–28)	(.97–1.83)	(11–33)	(12–43)	(0–55)
07	Red Lake	50°	93°	10	7	12	1.29	19	9	35
		80′	30′	(8–12)	(6–8)	(11–14)	(1.01–1.48)	(11–26)	(2–18)	(0–77)
09	Kenogami River	50°	84°	12	7	14	1.13	20	8	66
		60′	45′	(11–14)	(6–8)	(11–16)	(.89–1.25)	(18–26)	(0–22)	(9–97)
10	Moosonee	51°	80°	13	8	16	1.24	27	4	76
		25′	67′	(12–15)	(7–8)	(13–18)	(1.10–1.38)	(23–31)	(2–7)	(61–88)
12	Big Trout Lake	53°	89°	11	7	13	1.17	25	1	27
		83′	87′	(10–12)	(7–8)	(10–16)	(1.02–1.61)	(21–36)	(0–4)	(0–83)
14	Ft. Severn	56°	87°	12	7	16	1.28	29	<1	62
			67′	(10–15)	(6–8)	(13–19)	(1.22–1.40)	(25–33)	(0–2)	(29–83)

location were at least 5 km and usually over 10 km apart. Trees within stands were selected randomly with respect to cone and seed characteristics but were selected because they had at least moderate cone crops. Typically, trees were cut and all current year cones collected. Five of these trees from each of two stands in each provenance were selected for cone analysis, and 10 randomly selected cones from each tree were examined. Before drying, the length and width of these cones were measured with calipers. Each cone was then placed in an individual container and dried at room temperature to extract seed. After dissection to ensure that all seed had been extracted, the number of cone scales, seed, seed filled with a normal embryo and megagametophyte, and seed damaged by insects were recorded for each cone. Number of scales per unit of cone length and percentages of filled and insect damaged seed were computed for each cone. A nested analysis of variance of the form outlined in table 2 was used to evaluate variance in these characters accounted for by provenances, stands within provenances, trees within stands, and cones within trees, all considered as random effects. Tree means were used in computing correlation coefficients for the relationships presented in table 3.

Evaluation of variation in seed size was made using 10 to 20 randomly selected seed from 116 individual tree lots from the collection noted above (table 4). These seed lots were obtained from at least 100 cones per tree. Seed length and wing length

Table 3—*Coefficients of correlation among cone and seed characteristics of tamarack in northwestern Ontario*

	Cone width	Number cone scales	Number seed/cone	Percent filled seed
Cone length	.65**	.73**	.48**	.20
Cone width		.55**	.46**	.28
Number cone scales			.77**	.07
Number seed				.16

**Statistically significant at the .01 level of probability.

were recorded. Total seed length was computed as the sum of these measured characters. A nested analysis of variance based on 10 seed from each of 7 randomly selected trees per provenance (with two exceptions, see table 4) was used to assess variance associated with provenance, trees within provenance, and seed within trees (table 5). Coefficients used in computing variance components were adjusted for unequal sample size by the method of Snedecor and Cochran (1980).

Results

Cone length and width and number of cone scales, characters likely to be under relatively strong genetic control (Stoehr and Farmer 1986), varied little from provenance to provenance (tables 1 and 2). Effects of stands and trees within stands were statistically significant for all cone measurements except cone width, which did not vary significantly from stand to

Table 2—*Analyses of variance in tamarack cone and seed characteristics*

Source of variation	Degrees of freedom	Cone length		Cone width		No. scales per cone		Cone scales per mm		No. seed per cone		Arcsin % filled seed		Arcsin % seed insect damaged	
		MS	VC	MS	VC	MS	VC	MS	VC	MS	VC	MS	VC	MS	VC
Provenance	8	157.128	23	18.299*	15	345.261	8	0.796	21	1,797.190*	26	7,082.810**	31	8.499*	39
Stands/ provenance	9	66.573**	28	4.837	5	230.098**	25	0.512*	41	411.583**	9	1,159.430**	9	2.106**	17
Trees/stands	72	10.694**	25	2.979**	29	52.780**	34	0.238**	16	173.436**	29	275.379**	9	0.735**	38
Cones/trees	810	0.931	24	0.441	51	4.460	32	0.029	22	19.730	37	96.732	50	0.105	6

Expected Mean Squares

Provenance	$\sigma^2_C + c\,\sigma^2_T + ct\,\sigma^2_S + cts\,\sigma^2_P$
Stands/ provenance	$\sigma^2_C + c\,\sigma^2_T + ct\,\sigma^2_S$
Trees/stands	$\sigma^2_C + c\,\sigma^2_T$
Cones/trees	$\sigma^2_C + c$

MS = mean square, VC = variance component.
The variance component is expressed as the percentage of total variance.
*Statistically significant at the .05 level of probability.
**Statistically significant at the .01 level of probability.
σ^2_C = variance due to cones within trees
σ^2_T = variance due to trees within stands
σ^2_S = variance due to stands within provenances
σ^2_P = variance due to provenances
C = number of cones per tree
T = number of trees per stand
S = number of stands per provenance
P = number of provenances

Table 4—*Provenance means and range of tree means for seed dimensions of tamarack in northwestern Ontario*

	Source	Wing length (mm)	Seed length (mm)	Total length (mm)	Number of trees
02	Sault Ste. Marie	3.6 (3.1–4.7)	2.8 (2.6–2.8)	6.4 (5.8–8.0)	7
01	North Bay	3.4 (2.9–4.2)	2.5 (2.2–2.9)	5.9 (5.2–7.0)	8
05	Thunder Bay	3.5 (2.4–4.2)	2.7 (2.1–3.1)	6.2 (4.5–7.3)	15
06	Ft. Frances	3.4 (2.6–5.4	2.6 2.2–3.0)	6 (4.8–8.0)	19
07	Red Lake	3.1 (2.6–3.7)	2.4 (2.1–2.8)	5.5 (4.7–6.4)	16
09	Kenogami R.	4.2 (4.0–4.5)	2.6 (2.5–2.7)	6.8 (6.6–7.2)	3
10	Moosonee	4.1 (3.4–4.8)	2.7 (2.6–3.0)	6.8 (6.0–7.8)	4
12	Big Trout Lake	3.6 (2.7–4.5)	2.6 (2.2–3.0)	6.2 (5.1–7.3)	12
14	Ft. Severn	4.5 (3.7–5.5)	2.7 (2.0–3.2)	7.2 (5.8–8.3)	32

stand. This low level of stand variation within provenance in cone width resulted in a statistically significant F value for provenances, though provenance variation was low. Together, stands and trees within stands accounted for over 50% of variance in most of the cone size characters. Number of scales per unit of cone length followed the same pattern with wide tree-to-tree differences within provenances. Number of seed per cone was roughly double the number of scales for the three most northern provenances (Moosonee, Big Trout Lake, Ft. Severn) and Thunder Bay. For the remainder of the provenances, 71 to 79% of the seed sites (two per scale) were occupied. Provenance differences were larger for seeds per cone (16 to 29) than for other cone characters, though within-population differences accounted for most (38%) of the variance (table 2).

Percent of seed that were filled with an apparently viable embryo varied among provenances more dramatically than total number of seed, with the most northern provenance (Ft. Severn) having less than one percent filled seed (table 1). There was also a large degree (50%) of variation in this character among cones within trees. Maximum number of filled seed observed in single cones was ten to twelve. As expected, there were modest positive correlations between cone size (length and width) and total seed yield (table 3), but percent filled seed was not related to cone characteristics.

All three sampling levels accounted for significant variance in the degree of insect damage to seed, but the pattern of provenance variation did not follow the same pattern as percent filled seed since cones within trees accounted for very little variance (table 1). While a systematic evaluation of insect-specific damage to individual provenance samples was beyond the scope of this study, a specialist in conifer cone insects (Dr. Y. H. Prévost, School of Forestry, Lakehead University) did generally examine the sample and made the following observations. Most of the seed damage resulted from a furrow through seed produced by free-moving maggots, such as the larvae of *Earomyia aquilonia* McAlpine, which occur in tamarack. Secondly, seed coats were perforated by an exit hole such as those produced by a seed midge of the family Cecidomyiidae.

Provenance differences in total seed length (seed and wing) were not statistically significant, but there was a slight trend towards longer wing length in the three northern provenances within the Hudson Bay lowlands (tables 4 and 5). Most of the variation was related to seed size differences within trees, but significant differences among trees accounted for over 40% of the variance in total seed length.

Discussion

Analyses of cone and seed morphology revealed no major provenance differences or geographic trends and a preponderance of variance among

Table 5—*Analyses of variance in tamarack seed dimensions*

Source of variation	Degrees of freedom	Expected mean squares	Wing length: Mean square	Wing length: Variance component	Seed length: Mean square	Seed length: Variance component	Total length: Mean square	Total length: Variance component
Provenance	8	$\sigma^2_S + s\,\sigma^2_T + st\,\sigma^2_P$	235.31	2	45.3	1	468.36	4
Trees/provenance	52	$\sigma^2_S + s\,\sigma^2_T$	179.54**	41	39.44**	26	322.29**	43
Seed/trees	504	σ^2_S	21.59	56	8.77	73	35.24	53

Variance components are expressed as percentage of total variance.
**Statistically significant at the .01 level of probability.
σ^2_S = variance due to seeds within trees
σ^2_T = variance due to trees within provenances
σ^2_P = variance due to provenances
S = number of seeds per tree
T = number of trees per provenance
P = number of provenances

stands and trees within populations. In a recent related rangewide (New England to Alaska) study of tamarack leaf and cone dimensions, which included provenances in our sample, Parker and Dickinson (1990) noted that canonical variates analysis of nine cone traits resulted in only a weak geographical trend, though some of the northernmost Ontario provenances were separated from the main cluster. Studies of these characters in other north temperate and boreal conifers have shown a variety of patterns, from clear geographic trends (Borghetti et al. 1988, Simak 1967, Lester 1968) to minor unpatterned population differences (Khalil 1984, Bakowsky 1989, Parker and Maze 1984). Although geographic variation in cone morphology may be of little consequence in improving seed production, the preponderance of variance within populations in this study does have important implications in breeding. Genetic data on other boreal conifers, for example *Picea mariana* (Mill) B.S.P. (Stoehr and Farmer 1986), suggests that broad-sense heritability is moderately high for cone morphology. Therefore it appears that selection for large cones and large seed within populations of tamarack will be moderately effective in terms of increasing seed production.

This selection will result in larger numbers of seed per cone, but not necessarily an increase in number of filled seed, since, as our data show, the two characteristics are not related. Percentage filled seed in 1984 was significantly lower in northern provenances (lat. 51 to 56°) than in most of the southern provenances (lat. 46 to 49°), and there were broad tree-to-tree differences.

At least several factors are responsible for variation in percentage of filled seed. First, insect damage, which varies from year to year, was high in cones from some trees. For insect-damaged seed we were not able to distinguish normally filled seed from other seed. Thus the impact of this factor on filled seed cannot be separated from other factors. Second, many unsound tamarack seed have aborted embryos (Farmer and Reinholt 1986), which may be the consequence of inbreeding. Knowles et al. (1987) noted significant levels of self-fertilization in the seed lots used in this study, and Park and Fowler (1982) have shown that selfing reduces filled seed percent. The third factor, which may be particularly responsible for low filled seed percentages in northern provenances, is poor pollination and/or fertilization due to weather conditions. This factor, if it is operative, probably varies in impact from year to year. Brown's observation (1982) of year-to-year variation in percent filled seed in Alaska suggests that weather is an important determinant of seed yield. Payette and Gagnon (1979) and Payette et al. (1982) have shown that tamarack near the tree line in northern Quebec regenerate from seedlings, but their data indicate that percentage of filled seed may be generally low there. In short, while selection for increased number of seeds per cone will probably be effective, improving the quality of these seeds will likely require orchard management techniques such as improved pollination and control of cone insects.

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Tree Planter's Notes, Volume 42, No. 3 (1991)

Seed and Seedling Size Grading of Slash Pine Has Little Effect on Long-Term Growth of Trees

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Seeds from approximately 25 slash pine (Pinus elliottii Engelm. var. elliottii) trees were bulked, separated into three size classes, and planted in the nursery. Seedlings from each size class were graded into small, medium, and large size classes, and the resulting nine treatment combinations were planted in a randomized-block field design. Seed size had no significant effect on heights at outplanting (1 year from seed) or at three measurement ages (3, 10, and 15 years from outplanting) but did significantly affect survival and thus volume per plot at age 15. Seedling size affected heights at age 3 but the effect did not persist to ages 10 and 15 years. The only evidence of interaction between seed size and seedling size was for height and survival at age 3 years. Genetic identity in the study materials was not retained and may have masked the effects of seed and seedling size. Size grading of seeds or seedlings to control variation in long-term growth seems unnecessary for slash pine. Tree Planters' Notes 42(3) :23-27;1991.

Nursery managers separate seeds of coniferous species into size classes for more uniform sowing density, better synchrony in germination, and better control of seedling size. Also, seedlings may be separated into two or more size classes before field planting for easier handling and to reduce variation in survival and growth of the trees. However, it is not always clear whether grading seeds or seedlings according to size meets the desired objectives. Environmental conditions vary among planting sites. Seedlings best suited for one site may do poorly on a different site. Seedling traits other than size also may affect performance.

Separating seeds into size or weight classes is easy to do, but factors other than inherent growth potential of the embryo may affect seed size, such as seed maturity (Campbell and Sorenson 1984), cone size (Righter 1945), and mother tree (Brown and Goddard 1959). Consequently, though seedling size often is positively correlated with seed size, the association usually does not persist for more than a few years after seedlings are planted in the field (Belcher et al. 1984, Brown and Goddard 1959, Dorman 1976, Righter 1945). However, the correlation between seed size and tree height (Sluder 1979) or volume per acre (Robinson and van Buijtenen 1979) may persist for up to 15 years.

Seedlings usually are graded on height and/or root collar diameter. The relationship between morphological grade and subsequent field performance of seedlings has been more consistent than that between seed grade and performance. Large seedlings generally survive and grow better than do small seedlings (Burns and Brendemuehl 1971, Dorman 1976, Mexal and Landis 1990, Sluder 1979, South et al. 1985, Wakeley 1954, 1969). The physiological state of the seedlings also affects survival and growth, causing erratic response to morphological grading (Mexal and Landis 1990, Wakeley 1954). Also, though they generally grow better than short ones, tall seedlings may have low survival rates on some sites (Thompson 1985). Variation in inherent growth potential may be expressed later than the seedling stage, decreasing the long-term effects of seedling morphological grade (Righter 1945).

Although long-term correlations between tree height or volume per acre and seedling grade have been reported from several studies (Dorman 1976, Robinson and van Buijtnenen 1979, Sluder 1979, South et al. 1985, Wakeley 1969), few studies have investigated long-term effects of seed size on tree growth. The objective of this study was to determine the effects of seed and seedling size on slash pine survival and growth up to 15 years of age.

Methods

Seeds for this study were collected in 1952 from approximately 25 slash pine trees in plantations on Callaway Foundation land near Pine Mountain, GA. The single-tree seed lots were combined, then the bulk lot was separated into small, medium, and large size classes before planting in the nursery at Callaway in 1953. Seed size was not replicated in the nursery. After 1 growing season, seedlings from each seed size class were lifted and graded into small, medium, and large seedling size classes. No size specifications other than the words "small," "medium," and "large" were recorded for seeds or seedlings. The resulting treatments constituted a factorial combination of 3 seed sizes x 3 seedling sizes. Seedlings from the 9 treatments were outplanted in early 1954 in 4 randomized-block replications of 25-tree square plots of each treatment at a spacing of 10 by 10 feet on an old-field site on Callaway Foundation land. Included in each replication was a 25-tree plot of each of 3 ungraded control lots2 half-sib progenies grown in the same nursery as the study seedlings and a lot of seedlings procured from a commercial nursery.

Data recorded were heights at outplanting and at plantation ages 3, 10, and 15 years; survival at ages 3, 10, and 15; and diameter at breast height (dbh) and infection by southern fusiform rust at age 15. Heights were measured to the nearest 0.1 foot at the two younger ages and to the nearest 0.5 foot at ages 10 and 15. The data were subjected to factorial analyses that tested for significance of the mean effects of the two factors and their interactions as well as for their linear and quadratic effects and interactions. Bonferroni's multiple comparison method was used to separate outplanting mean heights of seed and seedling grades.

To determine whether seed and seedling grading affected height variation within treatment at age 15 years, within-plot coefficients of variation in height were calculated for each of the 9 factorial treatment combinations and the 3 ungraded control lots. Coefficients of variation for treatments were compared statistically with those for controls.

Table 1—*Mean initial seedling heights for the 9 treatment combinations of small, medium, and large seed and seedling sizes, at the time of planting*

Seed size	Initial height (ft) Small	Medium	Large	Mean
Small	0.72	0.86	0.92	0.83 a
Medium	0.73	0.87	0.99	0.86 a
Large	0.75	0.82	0.89	0.82 a
Mean	0.73 a	0.85 ab	0.94 b	0.84

Within a factor, means not followed by a common letter differ significantly at the 0.05 level (Bonferroni's multiple comparison method).

Table 2—*Analysis of variance of mean seedling heights at ages 1, 3, 10, and 15 years of trees from 3 seed sizes and 3 seedling sizes*[1]

Source	df	F values 1 yr	3 yr	10 yr	15 yr
Replication (R)	3	1.74	2.81	3.97	13.48**
Seed size (A)	2	2.36	0.24	0.87	0.09
Linear (A_1)	1	0.31	0.40	1.60	0.07
Quadratic (A_q)	1	4.41	0.08	0.14	0.11
Seedling size (B)	2	24.10**	4.98	0.93	1.21
Linear (B_1)	1	47.95**	2.38	0.35	2.14
Quadratic (B_q)	1	0.26	7.59*	1.50	0.29
A × B	4	0.84	2.80	1.97	1.31
$A_1 \times B_1$	1	0.77	1.44	0.03	3.45
$A_1 \times B_q$	1	0.39	1.51	1.83	1.25
$A_q \times B_1$	1	2.19	0.11	3.17	0.01
$A_q \times B_q$	1	0.01	8.13*	2.88	0.53
R × A	6	0.41	4.15*	1.78	1.38
R × B	6	0.95	1.72	5.13**	4.07

[1]Age 1 from seed, ages 3, 10, and 15 from outplanting.
*Significant at the 0.05 level.
**Significant at the 0.01 level.

Results

Seed size. Mean heights after outplanting of seedlings from the 3 seed sizes did not differ significantly (tables 1 and 2). Neither did seed size have any independent effect on tree height at plantation ages 3, 10, or 15 years (table 2, figure 1). It did, however, affect survival and thus volume per plot at age 15, with trees from medium-sized seeds tending to do poorest in both traits (figures 2 and 3). Neither dbh nor fusiform rust infection rates of the trees at age 15 were affected by seed size.

Seedling size. Mean outplanting heights for the 3 seedling sizes differed highly significantly (0.01 level), as expected (tables 1 and 2). The seedling size effect on tree height was still significant (0.05 level) at age 3 but not at ages 10 or 15 (table 2, figure 1). At ages 3 and 10 years, trees from medium-sized seedlings tended to be tallest, but by age 15 they were about intermediate in height to those from small and large seedlings (figure 1). There were no significant effects of seedling size on dbh or rust infection rate at age 15.

Interaction. Interaction between seed size and seedling size was confined to a significant (0.05 level) quadratic x quadratic interaction for height at age 3 (table 2). At that age, medium seedlings were tallest for the small and large seed sizes but were intermediate in height for the medium seed size (figure 1).

Variation within treatment. None of the mean within-plot coefficients of variation in height at age 15 for the 9 treatment combinations was significantly different from the CV for the commercial control. The coefficient of variation for the control was 10.79% and the coefficients for the 9 treatments ranged from 7.37 to 11.70% (mean 9.14%). One of the 2 half-sib progenies was significantly less variable in height than the commercial control; it had a coefficient of 5.94%.

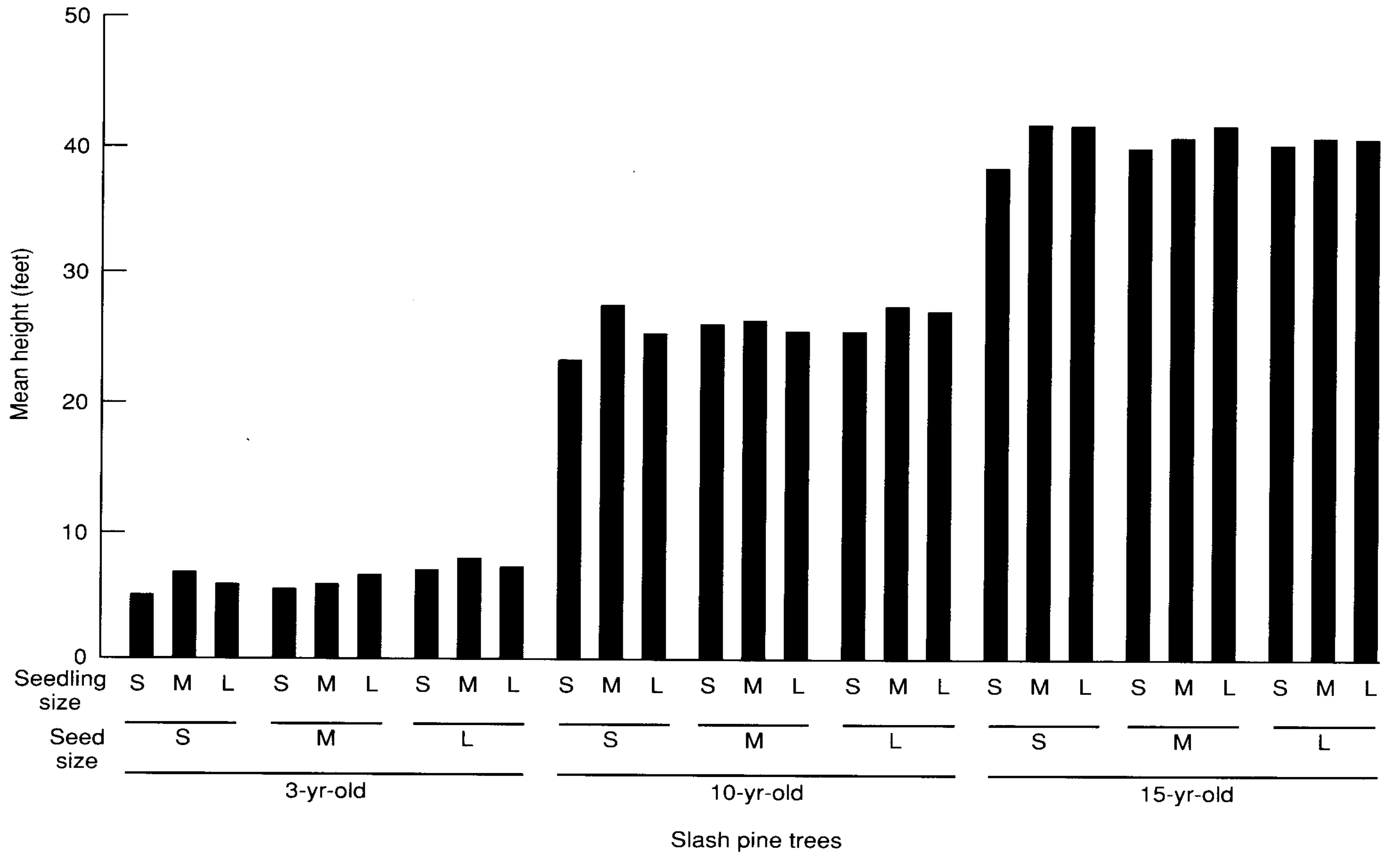

Figure 1—*Mean heights at ages 3, 10, and 15 years of slash pines from seeds separated into small, medium, and large classes and the seedlings from each size in turn graded into small, medium, and large size classes.*

Discussion

The performance of a tree, or a plot or stand of trees, is determined by genetic and environmental factors. Both kinds of factors may change over time. Genetic controls during the juvenile stage may differ from those of more mature stages. The competitive environment changes with tree size. Studies on the effects of nursery practices, some of which may have genetic implications (Campbell and Sorensen 1984), on tree growth and variation therefore need to be long term to allow time for these changes to occur and to interact. This study has been carried for 15 years, providing a good test of the long-term effects of seed and seedling size grading. Information is especially lacking for seed size.

Grading seeds and seedlings into size classes is advantageous to nursery and forest managers if it produces gains in uniformity of sowing density, germination rate, size of planting stock, or performance of planted trees. This study, as have many others, indicates that seed and seedling grading is not likely to produce undesirable results, so the cost of grading needs to be weighed only against expected advantages. Grading seeds should be easy to justify because it is a low-cost process. Grading seedlings, however, is expensive and, other than the benefits of discarding cull seedlings, probably won't produce significant gains in performance of planted trees.

The seed and seedling grading done in this study did not separate the trees into groups of uniform height growth. Even if grading does tend to separate seeds by maternal parent (Brown and Goddard 1959), each of the grades will contain seeds from a number of parents. Also, seed grading should have

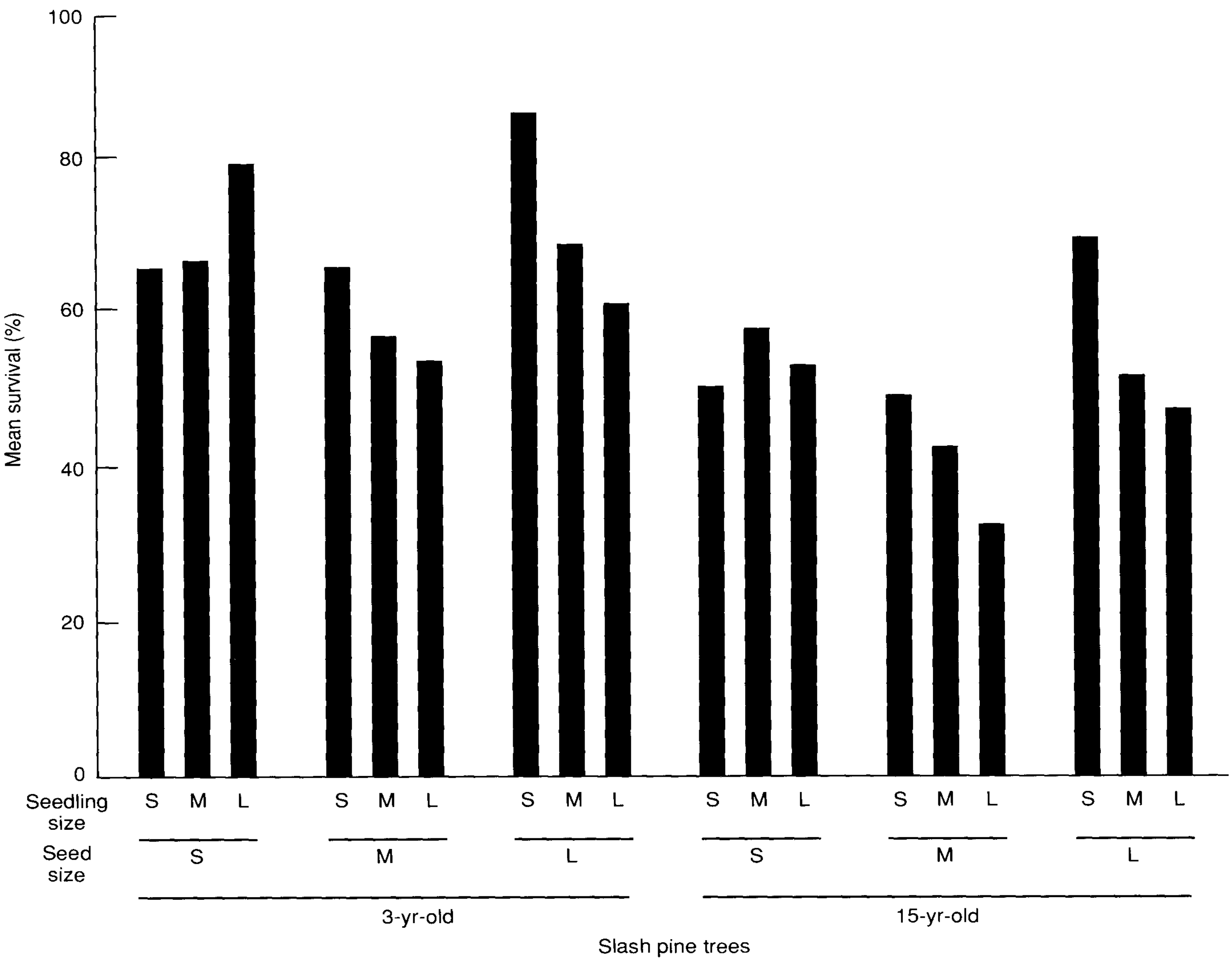

Figure 2—*Mean survival at ages 3 and 15 years of small, medium or large slash pine seedlings from small, medium, or large seeds.*

little or no effect on the paternal parent mix in each grade. Therefore, grading seeds from a bulk lot originating from a large number of parents should have little effect on variability of height growth within grades.

Even though height growth variation within seed or seedling grades may remain as high as that within ungraded lots, it is possible that genetic differences among grades in mean performance may occur in some traits. That did not occur for long-term height growth in this study, but it did for long-term survival as shown by a lower survival rate of trees from medium-sized seeds. There is no obvious reason why seed size per se should cause this difference. A more logical explanation is that seed size grading did tend to separate the seeds by mother tree and that at least one tree with predominantly medium-sized seeds produced seedlings that survived poorly after outplanting.

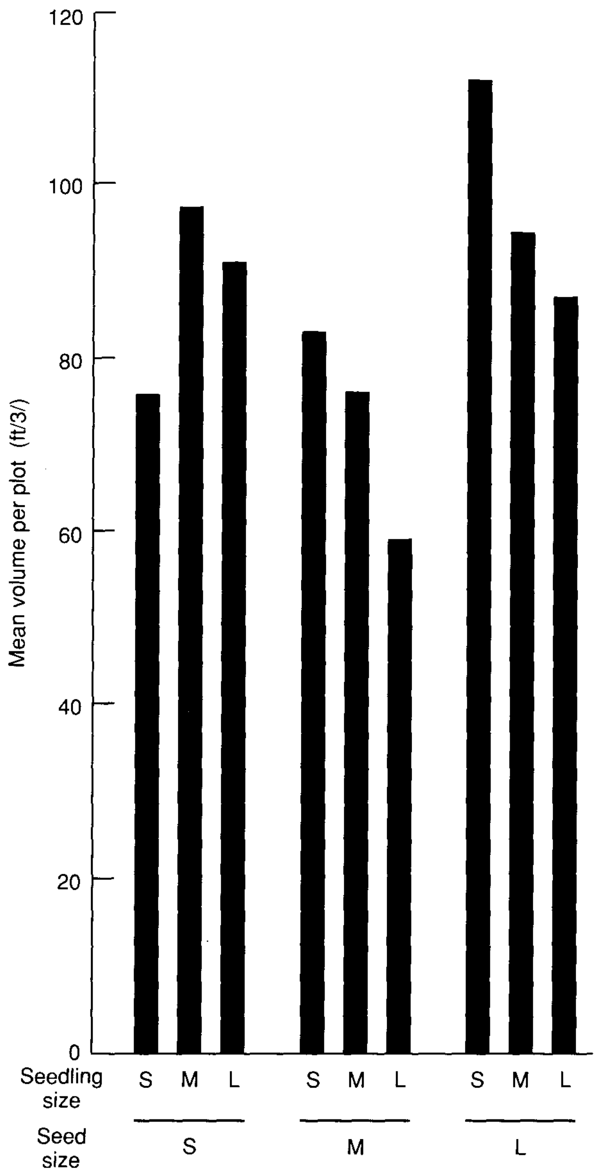

Figure 3—*Mean volume per plot at age 15 years of slash pine trees planted as small, medium, or large seedlings from small, medium, or large seeds.*

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Seedbed Densities and Sowing and Lifting Dates Affect Nursery Development and Field Survival of Longleaf Pine Seedlings

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Longleaf pine seedling development was markedly affected by seedbed densities: Larger and better quality stock resulted from lower bed densities. Seedlings lifted in December were markedly smaller if they had been sown in the spring rather than in the fall of the previous year; the smaller size produced lower field survival. Fall sowing resulted in greater seedling size and survival when lifting was done in December as opposed to February. When lifting was delayed until February, the effects of sowing dates declined. Tree Planters' Notes 42(3):28-31; 1991.

Longleaf pine *(Pinus palustris* Mill.) is potentially one of the most important pine species for reforestation in the southern Coastal Plain of the United States. Vast unspoiled tracts of longleaf pine previously existed across the South from eastern Texas to South Carolina. This species is characterized by its lack of regeneration on sites that have extensive amounts of competing vegetation. Longleaf pine has no early epicotyl growth and its peculiar "grass stage" contributes to its sensitivity to competition. Regeneration has become more difficult with the advent of fire control, and longleaf pine has failed to maintain its competitive position because of the rapid early juvenile growth of other southern pine species. Acreage in longleaf pine is now only about 10% of that in the original forest. However, there has been an increasing interest in the use of longleaf pine because of its resistance to insect and disease problems and to the high quality of forest products made from its solid wood.

One of the methods of improving reforestation success is to increase the quality of longleaf pine planting stock. Several nursery studies have shown the importance of such factors as seedbed density, dates of sowing, and culture treatments on quality of the planting stock (Derr 1955, Huberman 1938, Scarbrough and Allen 1954, Shipman 1958, Shoulders 1963, Wakeley 1954). Other studies have shown that seedling size and quality affect field survival and early height growth (Lauer 1987, White 1981). Seedling storage is another factor critical to the performance of longleaf pine planting stock and storability seems related to seedling morphology and physiology (Barnett et al. 1990, White 1981). Also, use of fungicides in the packing medium greatly improves the field performance after storage (Barnett et al. 1988). It has been demonstrated that selected nursery culture and seedling handling practices can markedly increase longleaf pine reforestation success (Cordell et al. 1990).

This study was initiated to clarify the relationships among seedbed densities, sowing dates, and lifting dates and their effects on longleaf pine seedling development and field performance.

Methods

Four randomized complete blocks with 25-foot-long plots for each of two sowing dates, two lifting dates, and three densities-10, 20, and 30 seedlings per square foot-were established at the W. W. Ashe Nursery at Brooklyn, Mississippi. Both fall (October 31, 1978) and spring (April 3, 1978) sowings were tested. The thinning necessary to bring the seedbed seedling densities into conformance with the appropriate density targets was done in late May, somewhat later than normal because of a wet spring.

All of the seedlings were undercut to a 6-inch depth on September 15 and November 1, 1979 and in addition, the seedlings scheduled to be lifted in February were root-pruned on December 15, 1979 to stimulate lateral root growth and to retard the devel-

Table 1—*Effect of sowing times, seedbed densities, and lifting dates on percentages of small (4 to 5 mm) and large (11 to 12 mm) longleaf pine seedlings*

Seedbed densities (seedlings/ft^2)	Percent of possible total seedlings/cell: December lift, Small	December lift, Large	February lift, Small	February lift, Large
Fall sowing				
10	7	19	5	20
20	23	11	11	17
30	12	11	17	15
Spring sowing				
10	18	9	8	17
20	18	5	15	11
30	25	3	20	8

opment of a long taproot. On December 12-13, 1979, and February 5-6, 1980, 200 seedlings were lifted from each test plot and graded according to root-collar diameter to obtain an estimate of the relative yield per grade as influenced by treatment.

Seedlings from the December and February lift dates were outplanted, 200 for each of the treatment replication combinations, in the same month that the lifting occurred. They were packed according to the operational system used at the nursery-clay slurry treatment in Kraft-polyethylene bags. The stock was outplanted by hand on the Palustris Experimental Forest in central Louisiana at a 2- by 2-foot spacing in the same experimental design as they were grown in the nursery. Survival determinations were made annually for 2 years following planting. Only results after the first year in the field are presented because of low survival due to one of the most severe droughts on record during the summer and fall after planting.

Statistical analyses of treatment means followed analysis of variance procedures with $P < 0.05$ level was used to test significance. Since all treatment effects and their interactions were statistically significant, no detailed statistical data are presented and the results are presented graphically.

Results and Discussion

Seedling development. Two major trends in seedling development are obvious from the data. First, seedbed density affected seedling size at the time of lifting. The percentages of small seedlings were much lower when they were grown at a bed density of 10 per square foot for both December and February lift dates (figure 1). The percentage of larger seedlings was greater at this low density. The highest density (30 per square foot) produced the smallest seedlings regardless of lifting dates (table 1), except for the fall sow/December lift.

Second, there was a relation between sowing dates and lifting dates. Seedlings lifted in December were smaller if they had been spring-sown rather than fall-sown (table 1), which confirms Shipman's (1958) conclusions that larger planting stock resulted from fall-sown pine seeds. However, when lifting was delayed until later in the season (February), the percentage of larger plantable stock increased significantly for both sowing times. The longleaf pine seedlings continued to develop in the winter months in this south Mississippi nursery. The size of planting stock increased when lifting was delayed from December to February, but the size differences were greater for spring-sown than fall-sown seedlings.

Seedling survival. Seedling survival of the planting stock was determined one full growing season after planting (figure 2). Because of the severe drought in the year following planting, seedling survival averaged 69 and 50% for December and February lifted stock when measured in the following July. By the end of the growing season, it had dropped to levels that were completely unacceptable for operational plantings. However, even though they must be interpreted with caution, the percentages still provide valuable insights into the effects of the treatments applied. The December planting survival was much greater than for the February planting. This most likely reflects the greater opportunity for the December-lifted trees to become established after planting before the severe drought occurred. Those December-lifted seedlings grown at lower seedbed densities from the fall sowing performed best (figure 2). Spring-sown, December-lifted plants were consistently poorer performers than fall-sown, February-lifted plants.

Although survival of December-lifted trees was better from fall sowing than spring sowing, February-lifted stock survived better when spring-sown (figure 2). This relationship is not fully understood; it may reflect the development of large seedlings that were more difficult to properly lift and plant when fall sowings were held until February. No physiological evaluations of the stock were made. Recent research has shown that the optimum "lifting window" for longleaf pine may be in early January and that the February lift date may have resulted in lower physiological quality (Brissette et al. 1988).

These results strengthen the earlier reports (Derr 1955, Huberman 1938, Scarbrough and Allen 1954, Shipman 1958, Shoulders 1963) that low seedbed densities are necessary to produce the best quality longleaf pine planting stock and they point out the merits of fall sowing. They also raise questions about the best lifting times for longleaf pine. Clearly, more research is needed in this area to identify the most appropriate lifting windows for longleaf pine.

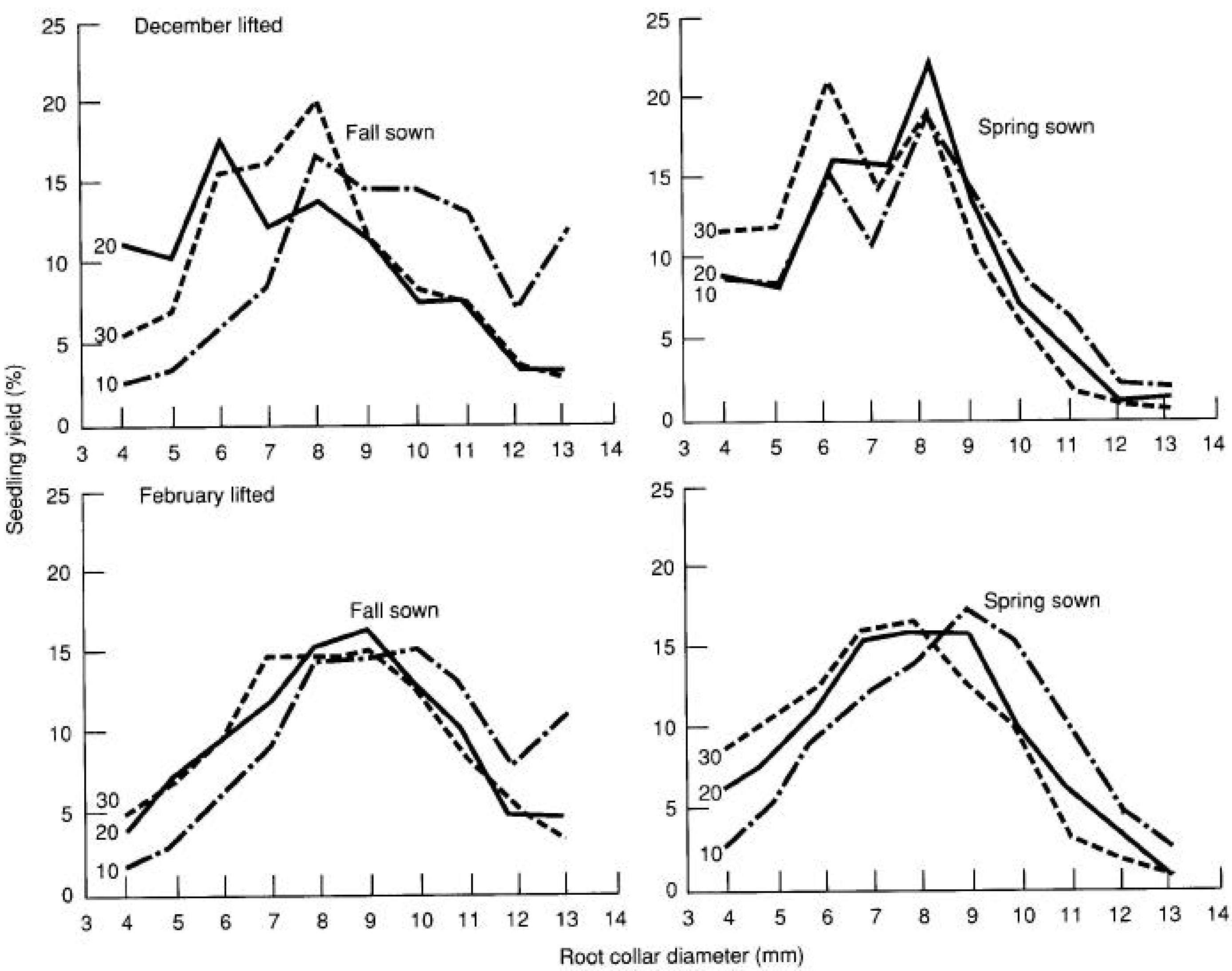

Figure 1—*Relative yield of longleaf pine seedlings by size of root-collar diameters as influenced by sowing date, lifting date, and seedbed density. The plotted percentages are for seedlings grown at 10, 20, and 30 per square foot, respectively.*

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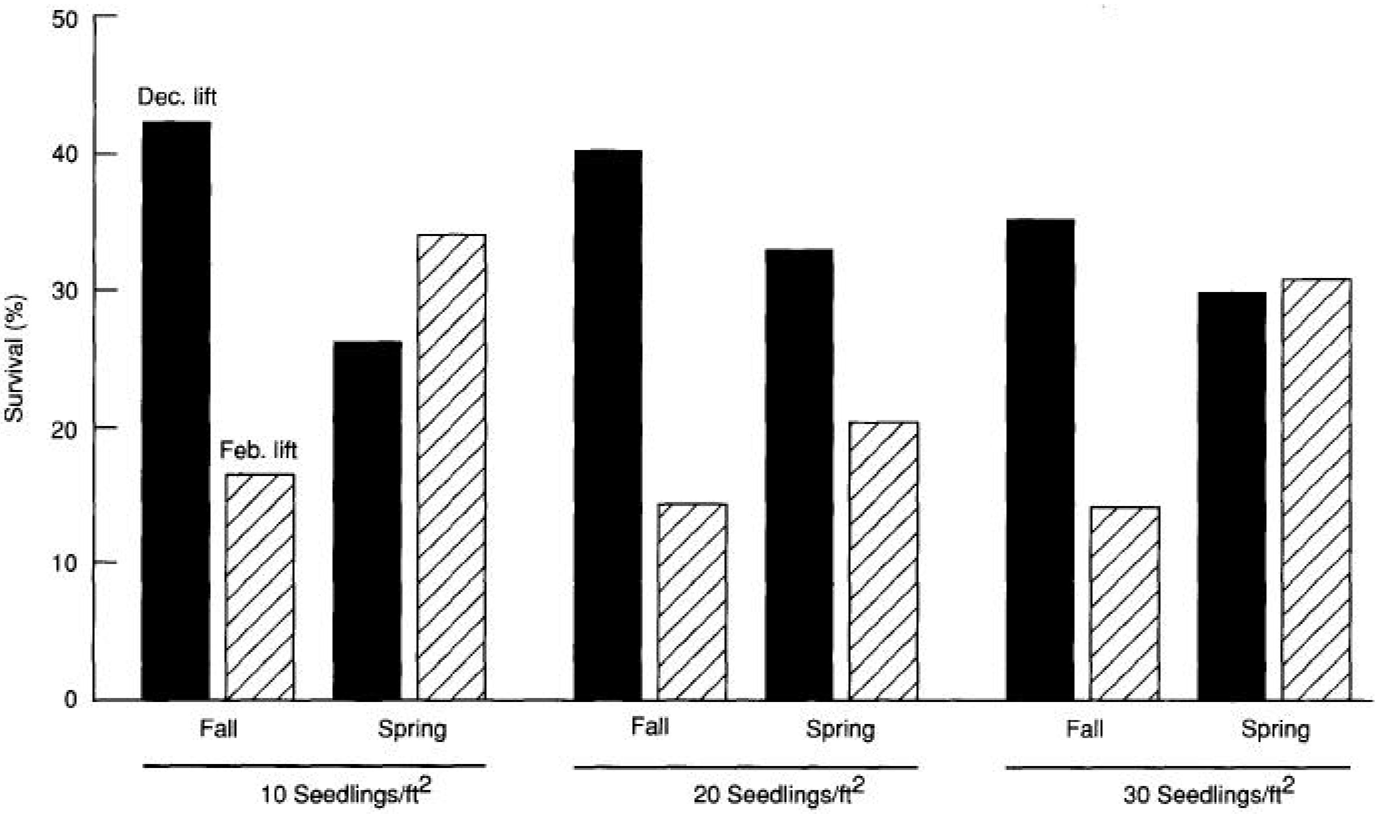

Figure 2—*Survival of longleaf pine seedlings as affected by nursery seedbed densities, dates of sowing, and dates of lifting.*

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Mulching Effects of Plant Fiber and Plant Fiber-Polyester Mats Combined With Fertilizer on Loblolly Pine Seedlings

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In this preliminary study, several mattings, combined with and without fertilizer application, were tested around newly planted loblolly pine (Pinus taeda L.) seedlings. After 9 months in the field, jute polyester and jute mats had similar survival rates relative to controls, but hemlock polyester mats had depressed survival when used in combination with fertilizer. All types of mats had similar durability--85 to 90% of them remained intact and stayed in place throughout the study. Fertilization generally increased seedling development but did not affect mat durability. Mats in combination with fertilizer did not affect seedling development. The mats provided 100% weed control. Tree Planters' Notes *42(3):32-35; 1991.*

Mulching newly planted seedlings may be a practical weed-control measure on southern pine sites and pastures being converted to pines, especially when herbicides cannot be used (Bengston *1969,* Bilan *1960,* Koch and McKenzie *1977,* Shekour et al. *1987,* Wolters *1972).* Forest litter and logging debris can be shredded on site to form a mulch or mulch can be transported from another site. Such natural mulch provides several benefits, including weed control, improved water retention in the soil, and reduced moisture stress for seedlings (Walker and McLaughlin *1989).* Natural mulch should also reduce erosion by wind and water, decrease sedimentation, lessen energy inputs for weed control, and alleviate non-point source pollution (Dao *1987).* It also restore the soil-air interface, which is often needed if cultural practices result in litter destruction, soil displacement, or compaction.

Another mulching strategy is to use manufactured matting that provides the benefits of natural mulch. Additionally, controlled-release fertilizers, animal repellents, insecticides, and herbicides might be selectively incorporated into the matting as needed. The combination of mulch and pesticides in agronomic crops has been promising (Banks and Robinson *1984,* Crutchfield et al. *1985,* Ghadiri et al. *1984),* and the addition of such chemicals might be based on silvicultural prescriptions to ensure seedling survival and early development on sites where nutritional deficiencies, animal damage, and insect and weed problems are expected to be especially severe. Also, the primary materials used in such mats are plant fibers, and therefore mats do not pose an environmental hazard as they decompose.

In this preliminary work, we studied plant fiber and plant fiber-polyester mats placed around the root collar of newly planted loblolly pine (*Pinus taeda L.*) seedlings and over a mowed cover of grasses (mostly *Andropogon* spp. and *Schizachyrium* spp.), forbs, and blackberries *(Rubus* spp.) Only a small quantity of the kinds of mattings tested were available, and we knew it would be difficult to detect positive growth responses among tree seedlings because of the small sample size. However, any negative effects from using the mats would probably be detected.

The objectives were to determine if

1. the mats remain intact and in place under field conditions (durability)
2. the mats benefit survival and development of planted loblolly pine seedlings
3. the mats control weeds
4. the combination of fertilizer and mats is especially beneficial

Methods

Fiber mat production. The mats were produced at the USDA Forest Service's Forest Products Laboratory in Madison, Wisconsin. The materials used were derived from jute (*Corchorus* spp.), western hemlock [*Tsuga heterophylla* (Raf.) Sarg.], and polyester. The jute was a bast fiber *3* to *4* inches long taken from the somewhat woody outer layer of the stem. The western hemlock was produced from 100% pulp-grade chips. The polyester fibers were *5.5* denier, *9.7* inches long, and crimped.

The fibers of jute, jute and polyester, or western hemlock and polyester were introduced into a turbulent air stream, transferred via this air stream to a moving support bed, and subsequently formed into a continuous, low-density mat of intertwined fibers that contained no adhesives. The weight per unit area of the mats was 0.030, 0.079, and 0.161 pounds per square foot for the 95%o jute/5% polyester, 100%o jute, and the 95% western hemlock/5% polyester mats, respectively. No adhesives were used. Further details are generally available upon request.

Study site. The site is gently sloping Beauregard silt loam (Plinthaquic Paleudults, fine-silty, siliceous, thermic) at the Palustris Experimental Forest, Rapides Parish, LA. Vegetation consists of established grasses, forbs, and blackberries. The plant cover was rotary mowed several days before the plots were installed, and weather data were available from a continuously recording electronic weather station located a quarter mile from the site.

Study design and analysis. In May 1989, four mat treatments and two fertilizer treatments were laid out in a 4 x 2 factorial experiment arranged in a randomized complete block design with 10 blocks serving as replications. A single loblolly pine seedling formed each of the 8 plots per block. The seedlings were grown in containers before planting. The blocks were planted by hand on May 25, 1989, with one of four half-sib families of 28-week-old pine seedlings that had been grown in containers. The total sample population was therefore 80 pine seedlings for the entire study.

In July 1989, seedling heights and groundline diameters were measured just before the mats and fertilizer treatments were applied. The mat treatments were (1) jute-polyester, (2) jute, (3) hemlock-polyester, and (4) controls (no mats). The fertilizer treatment consisted of a broadcast application of a commercial formulation of 13-13-13 N-P-K at 300 pounds per acre (39 pounds N, 17 pounds P, and 40 pounds K per acre) after the mats were placed around the pine seedlings. Controls received no fertilizer.

The matting was cut in 18- by 18-inch squares before being installed. Small mats were used because the amount of available hemlock-polyester material was limited. The mats were cut from one side to the middle so they could be fitted around the root collar of the pine seedlings. No hole had to be punched to make room for the seedling. Fertilizer was spread by hand over the matting on appropriate plots.

In April 1990, 1 year after outplanting, the final groundline diameter and height data for the loblolly seedlings were taken and the durability (ability to stay intact and in place) of the mats was visually evaluated: excellent, good, poor, or none remaining.

Analyses of variance ($P<0.05$) were used for seedling diameter and height comparisons. Mean differences, if present, were determined with Duncan's multiple range test ($P<0.05$). The durability results were arranged in contingency tables and analyzed by chi-square tests for independence ($P<0.05$). Seedling survival was evaluated by binomial distribution tests where the expected survival was 70% and the critical region was ±20% for each type of matting based on check results ($P<0.05$). In April 1990, competing vegetation was visually examined under each remaining mat.

Results and Discussion

Loblolly response and weed control. Loblolly pine survival was 80% or less for both non-matted and matted seedlings, even though rainfall was above normal in May (the seedlings were planted on May 25, 1989) and the weather was cooler and wetter than normal for 2 months after planting (tables 1 and 2).

The jute and jute-polyester mats did not influence survival relative to the controls (table 2). There was droughty weather in August and September 1989, and the mats were expected to improve survival over the checks by conserving water through weed control and reduced surface evaporation (table 1). However, the cool-wet weather in June and July 1989 probably allowed all surviving seedlings to establish themselves before the drought developed.

Table 1—*Monthly temperature and rainfall averages over the past 31 years, compared with average monthly ambient temperature and rainfall for the study period (from weather data collected at the Palustris Experimental Forest, Rapides Parish, LA)*

Months and activities	31-year averages: Ambient temp. (°F)	31-year averages: Total precip. (inches)	Averages during the study: Ambient temp. (°F)	Averages during the study: Total precip. (inches)
April	67	4.56	65	1.82
May	73	5.59	74	9.33
Planted seedlings 5/25/89				
June	80	3.62	76	13.75
July	82	3.97	79	6.35
Mats installed 7/31/89				
August	82	3.79	78	1.14
September	77	3.66	77	0.80
End of first growing season				
October	67	3.13	67	0.56
November	57	4.79	59	2.41
December	51	5.57	43	3.38
January	48	4.41	52	14.60
February	51	4.27	56	4.23
Beginning of second growing season				
March	59	3.95	61	6.41
April	67	4.56	66	3.27
Final measurements 4/25/90				

Table 2—*Mean loblolly pine seedling survival, groundline diameter (GLD), and height response to mulching with plant fiber and plant fiber-polyester mats, with and without broadcast fertilizer*

	At planting		Final measurement		
Type of mat	GLD (mm)	Height (cm)	Survival* (%)	GLD (mm)	Height (cm)
No fertilizer					
Jute-polyester	3 a	31 a	50 b	4 d	43 b
Jute	3 a	32 a	60 b	5 cd	42 b
Hemlock-polyester	3 a	31 a	60 b	5 cd	38 b
None	3 a	32 a	60 b	4 d	41 b
Fertilizer†					
Jute-polyester	3 a	32 a	80 b	7 b	45 ab
Jute	3 a	31 a	70 b	7 b	45 ab
Hemlock-polyester	3 a	32 a	20 a	8 ab	52 a
None	3 a	32 a	80 b	6 cb	46 ab

Pine diameter and height mean values in columns followed by the same letter do not differ significantly based on analyses of variance and Duncan's multiple range tests ($p < 0.05$).

*Results for seedling survival are based on binomial distribution tests where the expected survival was 70% and the critical region was ±20% for each type of matting based on check results ($p < 0.05$).

†The fertilizer used was a commercial formulation of 13-13-13 N-P-K at 300 pounds per acre (39 pounds N, 17 pounds P, and 40 pounds K per acre).

Hemlock-polyester mats reduced survival to 2 seedlings on the fertilized plots, but the surviving pines were the largest in the study (table 2). Reduced survival when fertilizer was used with the hemlock-polyester matting probably resulted from phytotoxicity associated with the mats rather than drought (table 1). Evidently, only larger than average seedlings will likely survive when the combination of fertilizer and hemlock-polyester matting is used.

No interactions of fertilizer and mat affected seedling development, possibly because the small sample size masked the interactive effects. This may be the case, for Bengston (1969) found that the combination of plastic mulch with fertilizer was especially beneficial over a 4-year period. Fertilization alone generally increased seedling development, as it normally does on this type of soil (table 2) (Shoulders and Tiarks 1983). The groundline diameters and heights of fertilized pine seedlings averaged 3 mm larger and 6 cm taller than those of unfertilized seedlings, respectively.

The mats had smothered the competing plants present at the time of installation, and no new weed growth or seed germination occurred under the mats. Although the mats were cut when they were placed around the pine seedlings, none of the grasses, forbs, or blackberries grew through the cut edge. Therefore weed control under the mats was 100%. Weed control is often correlated to increased growth, but height and diameter of checks was very similar to the matted treatments in the summer of their first growing season (table 2).

Mat durability. The three types of mats remained largely intact for the 9-month study period, and 85 to 90% remained in good-to-excellent condition (table 3). Therefore, excluding adhesives during manufacturing did not result in a loss of mat integrity, even though rainfall was above normal from October 1989 through April 1990 (table 1). The mat material was easily cut from the side to fit around the seedling root collar. Not having to punch a hole to make room for the seedling was a clear advantage over stiff materials that are difficult to puncture.

Animals, probably deer, disturbed some of the mats, apparently destroying 3 and damaging 5. However, there were no significant differences among mat types in terms of durability, and fertilizer did not significantly affect durability (table 3).

Table 3—*Evaluations of mat durability 9 months after placement around the root collar of loblolly pine seedlings using χ^2 tests of their heterogeneity**

	No. of mats			
Variables	None	Poor	Good	Excellent
Mat type (n = 20 mats per type)				
Jute-polyester	1	2	7	10
Jute	1	2	7	10
Hemlock-polyester	1	1	0	18
χ = 10.77††				
Fertilizer treatment (n = 30 mats per treatment)†				
None	3	3	8	16
300 lb. per acre	0	2	6	22
χ = 4.43††				

*Control results were excluded from these analyses because observations would be counted only in the none-durability class.

†The fertilizer used was a commercial formulation of 13-13-13 N-P-K at 300 pounds per acre (39 pounds N, 17 pounds P, and 40 pounds K per acre).

††The critical values ($p < 0.05$) of the mat and fertilizer comparisons are 12.59 and 7.82, respectively.

Conclusions

As outlined in our objectives, we reached several conclusions: (1) the mats were durable enough in the field to warrant more extensive testing, (2) the presence of the mats did not reduce loblolly pine seedlings survival, with the exception of the hemlock-polyester mat used in combination with fertilizer, (3) 100% weed control was maintained, and (4) the combination of fertilizer and mats was not generally better than fertilizer alone in this short-term study. Clearly, the negative effects of mats were minimal. A longer term study is needed to better assess the positive effects of mats on tree growth.

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