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Seedling Counter Field Tests

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In 1990 and 1991, the USDA Forest Service's Missoula Technology and Development Center (MTDC) conducted field tests at several USDA Forest Service nurseries to demonstrate how its seedling counter can automate the inventory process. During field tests, the counter was used to inventory most pine species (Pinus spp.) *as well as Douglas-fir* (Pseudotsuga menziesii *(Mirb.) Franco), California red fir* (Abies magnifica *A. Murr.), and Englemann spruce* (Picea engelmannii *Parry ex Engelm.). When inventories obtained with the seedling counter were compared to the those obtained by traditional hand-sampling methods, the seedling counter inventories consistently were within ± 10% of the nursery inventories for pine and fir species.* Tree Planters' Notes 44(1):8-12; 1993.

The seedling counter (figure 1) was developed by the USDA Forest Service Missoula Technology and Development Center (MTDC), in cooperation with Dr. Glenn Kranzler, Oklahoma State University, to count conifer seedlings in nurseries. It automates the inventory process, which traditionally has been accomplished by hand-counting samples within beds. The counter provides nursery managers with a tool for obtaining quick, reliable inventories.

The counter relies on custom-designed optoelectronics to detect and count seedlings. A portable computer controls the counting and records the data (figure 2). A single row of seedlings is counted in a bed with rows spaced 6 inches (15.2 cm) apart. The gross inventory for the lot can be estimated from the count obtained for one drill row. The more rows that are counted, the more accurate the estimate. Sowing with a precision seeder will improve counting accuracy, but it is not required. Acceptable accuracy can usually be obtained using the seedling counter on seedlings sown in a band with nonprecision seeders. Due to the configuration of the counter machinery, seedlings must be at least .08 inch (2 mm) in diameter and 2 inches (5.1 cm) in height to be counted (figure 3). Seedlings up to 2 feet (61 cm) tall can be counted.

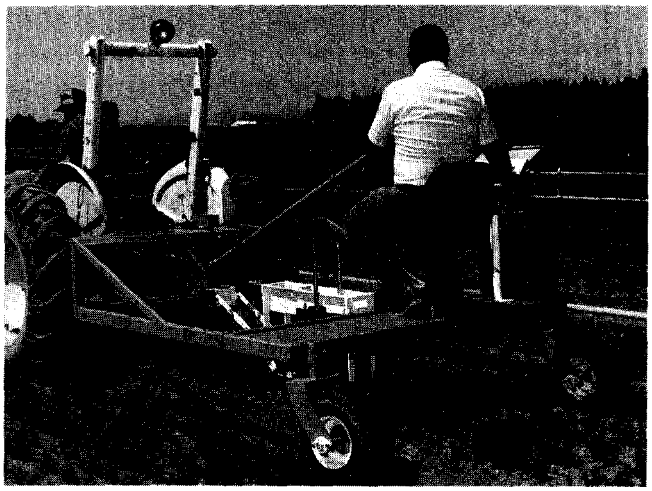

Figure 1—*The Missoula Technology Development Center's seedling counter.*

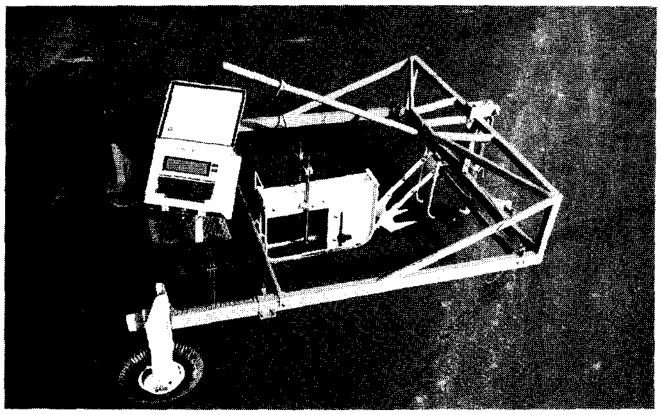

Figure 2—*A portable computer and opto-electronics combine to count seedlings.*

Before counting seedlings, the seedling counter must be calibrated for each species and size of species to be counted. During calibration, the length and width of the infrared beam is adjusted to obtain the most accurate count of the seedlings in a 20- to 30-foot (6.1- to 9.1-m) portion of a drill row, or a sampling of approximately 100 to 250 seedlings. Once the seedling counter is calibrated, many lots can be counted as long as the growth characteristics of the seedlings and bed conditions are similar to those of the calibration sampling. An

Figure 3—*Seedlings must be 2 mm in diameter and 5.08 cm (2 inches) in height to be counted.*

operator's manual describing the calibration in detail is available from MTDC.

The opto-electronics that detect and count the seedlings ride on a skid as the seedling counter is pulled along the nursery bed. Two skids are provided with the seedling counter. The skid marked "small" has a .04-inch-wide (1-mm-wide) infrared beam with five light segments. The skid marked "large" has a .08-inch-wide (2-mm-wide) infrared beam with six light segments. Each segment is 0.2-inch (.5-cm) tall. The large skid counts the 2+0 stock, transplants, and some large 1+0 stock. The small skid counts mostly 1+0 stock and smaller 2+0 stock. Seedling separators on the front of the skid help the operator distinguish drill rows in bushy stock. The separators will accommodate seedling rows sown on 6-inch (15.2-cm) centers in band widths to a maximum of 2 inches (5.1 cm).

Originally three seedling counters were constructed. One was delivered to the W.W. Ashe Nursery at Brooklyn, Mississippi, in the fall of 1988. Another was delivered to the Lucky Peak Nursery in Boise, Idaho, in the spring of 1990. The third has been used for trials and demonstrations by MTDC personnel. Six additional seedling counters have been constructed by MTDC in FY 1992 for Federal forest tree nurseries. All trials with the seedling counters were compared to 100% counts done by hand in the usual manner by nursery personnel.

1990 Field Tests

In September, 1990, the seedling counter was demonstrated at the Forest Service Bend Pine, Humboldt, and Placerville Nurseries (table 1).

Table 1-Conifers species used in field tests of the MTDC seedling counter

Common name	Scientific name
California red fir	*Abies magnifica* A. Murr.
noble fir	*Abies procera* Rehd.
Engelmann spruce	*Picea engelmannii* Parry ex Engelm.
lodgepole pine	*Pinus contorta* Dougl. ex Loud.
Jeffrey pine	*Pinus jeffreyi* Grev. & Balf.
ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.
western white pine	*Pinus monticola* Dougl. ex D. Don
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco

Bend Pine Nursery, Bend, Oregon. At Bend Pine Nursery the counter was used to inventory 1+0 and 2+0 ponderosa pine and 2+0 lodgepole pine. The discrepancy between the nursery inventories and estimated inventories obtained with the seedling counter was about 15% for the 1+0 and 2+0 ponderosa pine. The discrepancy was less than 9% for the 2+0 lodgepole pine inventories. Each seedling sample count (both by humans and by machine) exceeded 44,000 seedlings.

Sand castling, where the irrigation sprinklers washed soil into mounds around the seedlings, made it difficult to count the 1+0 ponderosa pine. Sand castling makes it difficult to find a height for the light beam above the sand castle but not above the shorter trees. Sand castling could be reduced or eliminated by using different irrigation techniques or applying Geo-Tech. With this change, 90+% accuracy could be obtained. In the 2+0 ponderosa pine, there was a significant number of short seedlings-3 inches (7.6 cm) and smaller. Although these seedlings would no doubt be culled, they were included in the calibration tests. If these had not been included, the seedling counter would have produced an inventory number more comparable to the hand-counted inventories. The 2+0 ponderosa pine was counted with 90+% accuracy when the small seedlings that are routinely culled were not included in the hand count. The 2+0 lodgepole was counted with 90+% accuracy.

Humboldt Nursery, McKinleyville, California. At Humboldt Nursery the counter was used to inventory 1+0 and 2+0 Douglas-fir (table 1). Each sample (both human and machine counts) exceeded 28,000 seedlings except one, which was the 1+0 Douglas-fir count of about 7,000 seedlings each. The large skid worked well for counting 2+0 Douglas-fir. The small skid worked well on the 1+0 Douglas-fir. However, some difficulties were encountered. For the 1+0 Douglas-fir, two machine inventories were considerably lower than the hand inventories, probably because of the large variation of the stem diameters. The calibration was done in locations comprised of mostly large caliper seedlings. But, these lots also had a substantial number of small caliper seedlings. Although it would be difficult to calibrate for the size variation, the size difference could be minimized by counting the trees earlier in the season while the seedlings are more uniform. In the 1+0 Douglas-fir, 85+% accuracy was obtained. The 2+0 Douglas-fir was very tall and bushy, which made it difficult for the skid to go down a row without running over the branches and pushing the seedlings down. A path breaker has been developed and appears to successfully eliminate the problem. The 2+0 Douglasfir were quite bushy and tall, over 24 inches (61 cm) in places, and made it very difficult to tell when the skid was centered in the row.

Placerville Nursery, Camino, California. At Placerville Nursery the counter was used to inventory 1+0 ponderosa pine, 2+0 Douglas-fir, and 2+0 Jeffrey pine. Each sample exceeded 6,000 seedlings except a 1+0 ponderosa pine test, which had about 2,000 seedlings in each of the human and machine testing phase. The small skid worked well for counting the 1+0 ponderosa pine. The large skid worked well for the 2+0 Douglas-fir. The large skid did very well on the 2+0 Jeffrey pine. The extreme slopes and sidehills at this nursery were not difficult for the seedling counter.

There were some large differences between the nursery inventories and the counter inventories. The 1+0 ponderosa pine and 2+0 Douglas-fir beds had not been weeded before the machine counting and made the accuracy of the seedling counter erratic. Discrepancies between the inventories ranged from 1 to 39%. Often, when the skid encountered a weed, the weed would roll the trees over, which caused them to lean forward. With the trees leaning forward, the infrared beam would produce false counts and detect unrealistically large calipers. Only two of eight rows in the bed were counted. Thus, any error in the count due to a weed was magnified four times. On small lots, this error can be a significant percentage of the total inventory. This is supported by the counter results. The small 1+0 ponderosa pine and the small 2+0 Douglas-fir had fairly high discrepancies. As the lot sizes increased, the errors decreased. It would be advantageous to count more rows of the bed in such smaller lots.

The 2+0 Jeffrey pine lot resulted in the most accurate inventory at any of the nurseries (99% accuracy). Bed conditions were ideal. The trees were approximately 7 inches (17.8 cm) tall, and there was little variation in height or caliper. These conditions permitted accurate calibration and high counting accuracy resulted.

1991 Field Tests

In July 1991, the seedling counter was demonstrated at the J. Herbert Stone and Wind River Forest Service Nurseries. MTDC added seedling separators to the front of the machine to help the operator distinguish between drill rows in bushy stock.

J. Herbert Stone Nursery, Central Point, Oregon. At J. Herbert Stone Nursery the seedling counter was used to count 1+0 and 2+0 ponderosa pine, 2+0 lodgepole pine, 2+0 ponderosa pine, 2+0 Douglas-fir, 2+0 Jeffrey pine, and 1+1 Douglas-fir. All tests involved at least 11,000 seedlings, except for 2 comparisons. The seedling counter did well in most of the species and sizes of seedlings counted (figure 4). The seedling counter inventories were within ± 10% of the nursery's hand-counted inventory in all cases except two lots of 2+0 Douglas-fir. Most seedling counter inventories com pared within ± 5% of the nursery inventories.

The 1+0 ponderosa pine provided the most challenge for the seedling counter. These seedlings were between ¾ inch (1.9 cm) and 2 inches (61 cm) tall and the bed had a soft layer of much on top. There were two portions to this lot. The first portion had a density of approximately 20 trees/square foot (1 square foot = .09 M^2). The second portion had a density of approximately 10

Figure 4—*The counter successfully counted most species and sizes of seedlings.*

trees/square foot. The seedling counter undercounted the lower density portion by 5.8%. This error could be reduced by counting the seedlings a month later in the season when they are likely to be at least .08 inch (2 mm) in diameter and 2 inches (5.1 cm) high. Estimated inventories for 1+0 ponderosa pine, 2+0 lodgepole pine, 2+0 Jeffrey pine, and 2+0 ponderosa pine compared within 5% of the nursery's hand-counted inventories. The count of the lot of 2+0 lodgepole pine was repeated to test the repeatability of the seedling counter. The estimated inventory in both cases was 2.5% under the nursery's gross inventory. The test showed that the seedling counter can be repeatable and accurate.

The estimated inventory of one lot of the 1+1 Douglas-fir transplants differed by 8% from the nursery inventory. This could be reduced by selecting a different row to count in each bed. This was done in the second 1+1 Douglas-fir lot. One row in each of the six beds was counted. The six rows were a mixture of inside and outside rows of the bed. The difference in inventories for this lot was an acceptable 1.2%. Mixing the rows counted from various inside rows and outside rows will increase accuracy.

The greatest differences occurred in the tall 2+0 Douglas-fir. In the lower density portion of the 1+0 ponderosa pine, a 9.1% discrepancy resulted between counter and hand-sampled inventories. The drill row count was within 2.5% of the 100% hand sampling. Counting more rows and counting these trees later in the season would reduce the difference. Even a small inaccuracy in counting only one row can be quite significant in a small lot. At the time of counting, the trees were taxing the physical limitations of the skid because they were from ¾ inch (1.9 cm) to 2 inches (5.1 cm) in height. Waiting 2 to 4 weeks before counting these trees would have improved counting accuracy.

Two counts of the 2+0 Douglas-fir produced estimated inventories 6% over and 13.9% under the nursery's gross inventory. On the first count, the operator crossed over from row no. 3 to row no. 4. On the second count, only row no. 3 was counted. The count of row no. 3 produced a count that was within 2.5% of the hand sample. The high and low estimated inventories indicate a wide variation of seedling density between rows. The difference in the inventory numbers could be reduced by counting more rows.

The 2+0 ponderosa pine provided an example of how varying row densities can affect the estimated inventory. The drill row count was within 2.5% of a 100% hand sampling of the drill row. The estimated inventory based on one or two row samplings differed by +20%. By counting every row of the lot, the seedling counter inventory differed from the nursery inventory by -0.4%.

Wind River Nursery, Carson, Washington. At Wind River Nursery, the seedling counter was used to count 1+0 ponderosa pine and noble fir; 2+0 ponderosa, white, and lodgepole pines; 2+0 Douglas-fir and California red fir (also known as Shasta fir); and 2+1 Douglas-fir and Engelmann spruce (table 1). All comparisons exceeded 3,000 seedlings for each type of inventory. During MTDC's visit to the nursery, bed conditions were not ideal. Many of the 2+0 beds had recently been pruned vertically or brush cultivated. This resulted in clumps of soil on the bed surface. In addition to the unsuitable bed surface conditions, the beds were extremely weedy. The counter cannot distinguish a green, healthy seedling from a brown seedling, weed, or marking stake.

The best results were obtained in the 2+0 ponderosa pine, 2+1 Douglas-fir, and the 2+0 Douglas fir. Estimated inventories for the 2+0 lodgepole pine and the 1+1 Douglas-fir were within 4% of the gross inventories. Estimated inventories of three lots of 2+0 Douglas-fir were within 4.3 to 6.1% of the gross inventories. One lot of 2+0 Douglas-fir was counted twice. The two estimated inventories differed from the gross inventory by 6.1 and 4.3%. This would indicate the seedling counter was counting consistently. The seedling counter also did well in the 2+1 Engelmann spruce. The estimated inventory was within 7% of the gross inventory. The estimated inventory was based on the average of four counts of the same drill row. All the weeds were pulled from the drill row before counting. This bed tested the capability of the seedling counter on sloping terrain. The bed had an initial 5% downgrade, an intermediate flat spot, and a final 2% upgrade.

Direction of travel while counting on sloping terrain appeared to affect the count. A southbound direction of travel produced counts that were consistently higher than the counts obtained on a northbound direction of travel. On level terrain, the main stems of the trees are fairly perpendicular to the bed surface. The skid was designed so the light beam would remain perpendicular to the bed surface as it is pulled down the bed. On sloping terrain the tree stems grow at a slight angle with respect to the bed surface. To keep the light beam aligned with the tree stems during counting, the operator would tilt the skid backward or forward slightly with a foot or hand. Tilting the skid and counting more rows in both directions of travel should produce reasonably accurate counts on sloping terrain. The seedling counter was difficult to calibrate on a bed with more than a 2% grade. This was probably due to the "lean" of the trees with respect to the bed surface. Calibration had to be performed on a level portion of the bed.

The estimated inventory of the 2+0 western white pine was within 9% of the gross inventory. The seedling counter was calibrated within 3% and four rows were counted. A small error in the hand count might have contributed to the slightly high discrepancy between the inventories.

Bed conditions were not ideal in the 2+0 California red fir or the 2+0 ponderosa pine. Both lots had many fairly mature weeds. The seedling counter was purposely calibrated low (17%) in the 2+0 California red fir to exclude the weeds from the count. As a result, the estimated inventory differed from the gross inventory by -22.8%. This difference might also be influenced by the variation in drill row density. The adjusted counts of the two drill rows counted were 743 and 952. The inaccuracy obtained in the two rows could be magnified four times in the estimated inventory. In the 2+0 ponderosa pine, the seedling counter was calibrated within 3%. The estimated inventory and the gross inventory differed by 16.4%. The row density appeared fairly consistent across the four rows counted. The discrepancy between the estimated and gross inventories was lower than that for the 2+0 California red fir. Some of the difference might be from inaccurate hand counts.

The 1+0 ponderosa pine and the 1+0 noble fir were too small for the seedling counter to count. The seedling counter was marginally successful in the 1+0 ponderosa pine. It was calibrated within 4% using two beam segments. Even so, the inventory was underestimated by 11.8%. The seedling counter was not at all successful in the 2+0 noble fir. The best calibration factor obtained was 44% using two beam segments. This resulted in a 32% difference between the estimated and gross inventories. Only two rows of the bed were counted. Counting more rows of the bed would probably not help reduce the error as much as counting the trees later in the inventory season.

Conclusions

To obtain the best results with the seedling counter, the inventory should be timed to count the seedlings when they are within the size limits of the machine. This will be more important with the very large, very small, or very bushy stock. It would be advisable to start the inventory in the taller, bushy stock. The rest of the 2+0 stock and the larger 1+0 stock should be counted next. The small 1+0 stock should be counted last. Nurseries might duplicate the seedling counter inventories with the traditional inventory process until confidence in the machine and its operator is established.

Field testing has shown that the MTDC seedling counter can successfully automate the seedling inventory process and should perform well in most pine and fir stock.

Nurseries will have to coordinate their inventory with their cultural practices. Beds should be weeded and dry for best results and the bed surface should be free from disturbance by vertical pruning or brushing.

Some experimentation may be necessary to find the best technique to eliminate the influences of sloping beds.

When results from 1990 and 1991 were compared, it was evident that user experience is a facfor in obtaining consistently acceptable accuracies with the seedling counter.

MTDC will continue to test and make appropriate modifications to insure the efficiency of the counter. For information on the seedling counter, contact Dave Gasvoda, Project Leader (406) 329-3986. Drawings, an operator's manual, a complete report on counter field tests, and a video may be requested from:

USDA Forest Service
Missoula Technology and Development Center
Building 1, Fort Missoula
Missoula, MT 59801

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Cover: Hoback River on the Bridger-Teton National Forest in Wyoming (R.E. Grossman, USDA Forest Service).

Comments

Methyl Bromide-We Can Learn to Live Without It!

Let's be realistic-methyl bromide is on its way out. It's just a question of time. Do you remember DDT? It was *the* broad-spectrum insecticide for many years until Rachael Carson blew the whistle in 1962. We learned, very quickly, that other chemicals could do the job, with much less impact on the environment.

The scientific data on this issue may be cloudy, but the political agenda is clear. EPA has called for a phase-out of all chemicals that may deplete the ozone layer by the year 2000. There are other factors-some political, some emotional-that may produce an earlier cancellation.

Faced with this situation, let's look at our alternatives. Methyl bromide is an effective soil fumigant in forest tree nurseries. It is the chemical of choice for controlling a wide array of soil-borne pathogens (for example, *Cylindrocladium, Fusarium, Macrophomina, Phytophthora,* and *Rhizoctonia* species). It is also effective in the control of some difficult weeds, such as nutsedge *(Cyperus* species) and prostrate spurge *(Euphorbia supina L.).* It should be pointed out, however, that herbicides are available for the control of some of these weeds and that herbicides are much safer to use and are more cost-effective than methyl bromide. An integrated pest management approach can also be used to minimize the need for soil fumigants.

In the absence of methyl bromide, consider the following management strategies in your nurseries:

- *Carefully match the species to the nursery site.* Grow bottomland hardwoods in the wetter compartments and pines in the drier areas. Pay close attention to soil pH and the preference of the species for soil acidity as well as soil texture and drainage.
- *Rotate the crops on a systematic basis.* Choose cover crops that reduce pathogen populations rather than build them up.
- *Map your nursery annually, with special emphasis on the chronic problem areas.* Consider infrared aerial photos to document trouble spots.
- *Pay close attention to good drainage.* Many root disease problems can be avoided by improving soil drainage. Use subsoiling, deep plowing, land shaping and ditching to improve drainage. Consider tile drains in difficult areas. Avoid soil compaction throughout the nursery.
- *Maintain high levels of organic matter in the soil.* Organic matter offers many benefits, including improved cation exchange capacity, improved soil texture, and improved lateral root and mycorrhizal development. Also, organic matter often promotes soil-borne microorganisms that suppress the activity of pathogenic fungi.

- *Practice judicious weed control throughout your nursery.* This includes good sanitation in non-production areas as well as the seedbeds. Riser lines, alleys, and other non-production areas must be kept weed-free to prevent weed seed dispersal throughout the nursery
- *Grow your seedlings at low density.* Larger root systems produce more vigorous seedlings, which are resistant to many pathogenic organisms.
- *Select clean, pathogen free mulch.* Mulch materials are often a source of weed seeds and spores of pathogenic fungi.
- *Provide optimum conditions for both ecto- and endomycorrhizae.* Mycorrhizae play an important role in forest tree nurseries. In addition to their nutritional benefits to the host seedling, mycorrhizae often have the ability to repel pathogenic fungi in the soil.

Perhaps the most difficult decision to be faced is what to do about the chronic, persistent diseases that are endemic in some nurseries. In the absence of methyl bromide there appear to be three alternatives:

1. Use an alternative fumigation material (for example, Dazomet, etc., or possibly chloropicrin) when needed. Be sure to follow the label carefully.
2. Try solar tarping-it can be effective under the right conditions.
3. If all else fails-move out of these disease-prone areas.
4. Apply pressure to the agricultural chemicals manufacturers to develop new, effective, *and* environmentally safe fumigation chemicals.

There will be some difficult situations. Perhaps some nurseries will even be quarantined. But nursery managers are a determined, clever, and resourceful group. They will accept the challenge and win.

Clark W. Lantz
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Scarifiers for Shelterwoods

Dick Karsky

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Three scarifiers have been modified to provide natural regeneration in shelterwoods. The Salmon blade, an anchor chain, and a three-point hitch-mounted disk were made lighter, smaller, more compact, and more manuverable. They can achieve 50 to 60% scarification and can mix the top 2 inches (5 cm) of soil with duff while avoiding damage to residual root systems. The scarifiers performed well in field tests in the Great Lakes States and are available commercially. Tree Planters' Notes 44(1):13–15; 1993.

A Salmon blade, an anchor chain, and a three-point hitch-mounted disk have been modified to scarify the soil for optimum natural regeneration in shelterwoods. The equipment was designed to benefit hardwood regeneration in the Great Lakes States, but the scarifiers have potential for other site preparation work. The scarifiers are capable of achieving 50 to 60% scarification and can mix the top 2 inches (5 cm) of soil with duff while avoiding damage to residual root systems. The scarifiers are light, compact enough for use in partially cut stands, and offer good maneuverability.

The Missoula Technology and Development Center (MTDC) worked with representatives from the Chequamegon and Nicolet National Forests in Wisconsin (Eastern Region), as well as the North Central Forest Experiment Station's Grand Rapids Science Laboratory, and members of the Lake States Silvicultural Cooperative to provide adequate seedbed preparation for paper birch (table 1), which thrives in the moist, cool conditions of New England but requires help to regenerate in the drier, warmer edges of its range in the Great Lakes region. To ensure seed germination and seedling survival under these marginal conditions, downed seeds and surface litter must be mixed with the decaying organic matter and underlying mineral soil. MTDC engineers modified three scarifiers used in Northwest regeneration projects. The scarifiers were made smaller, lighter, more compact, and more maneuverable.

Table 1—*Shelterwood species used in scarifier trials in the Great Lakes area*

Common name	Scientific name
yellow birch	*Betula alleghaniensis* Britton
paper birch	*Betula papyrifera* Marsh.
eastern hemlock	*Tsuga canadensis* (L.) Carr.
northern red oak	*Quercus rubra* L.
eastern white pine	*Pinus strobus* L.
northern whitecedar	*Juniperus virginiana* L.

The modified scarifiers were evaluated during the 1991 field season. Shelterwoods of paper birch and white pine on the Chequamegon and Nicolet National Forest test sites were 5 to 40 acres (2 to 16 hectares) and had slopes of up to 20%. Preliminary data show good results for the modified scarifiers. The scarifiers should be effective tools for reestablishing yellow and paper birch, northern red oak, eastern white pine, eastern hemlock, and northern whitecedar (table 1).

Modified Salmon Blade

The modified Salmon blade (figure 1) is designed for use with a John Deere Model 450/550, 60- to 80-horsepower crawler-tractor. It holds excellent promise for shelterwood scarification on small, partially cut sites. Preliminary reports indicate good scarification and soil mixture during field tests.

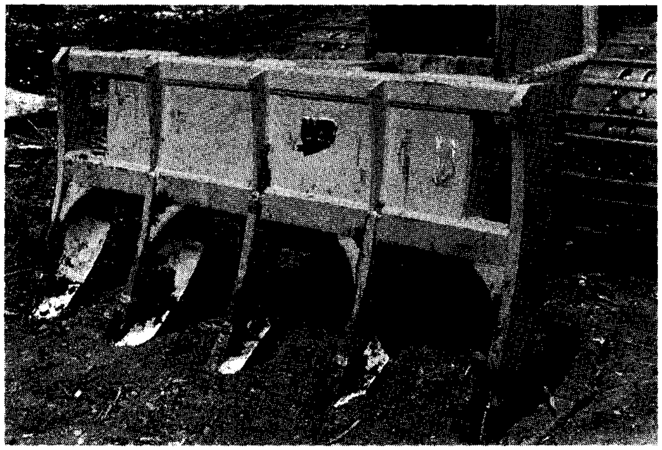

Figure 1—*Front-mounted Salmon blade for small crawler-tractors, including cultivator inserts on each prong.*

The modified blade is 30 to 40% smaller than the original machine built by the Salmon National Forest in Idaho. This smaller blade increases maneuverability in small spaces. The smaller blade is easy to mount and fits the smaller crawler-tractors used in this work. It can effectively undercut competing vegetation, which results in less grass invasion and increased regeneration. Both the original and the modified Salmon blades are capable of piling or scattering slash. The cultivator inserts provide good soil mixture. The cultivator inserts create furrows to catch seed and hold water that provides a microsite for regeneration. Penetration level can be controlled by varying the blade depth. One trip over an area can produce adequate soil disturbances for seedbeds. The modified Salmon blade is not recommended for slopes exceeding 35%.

The 6.5-foot-wide (2-m-wide) modified blade costs about $7,000. It weighs 1,400 pounds (636 kg) and is available from the manufacturer at the following address:

Weldco-Beales
2328 Roosevelt Avenue
PO Box 8
Enemclaw, WA
(206) 825-3581

Modified Drag-Chain Scarifier

The modified drag-chain scarifier (figure 2) is smaller than the original anchor-chain scarifier that was developed in British Columbia, Canada, for post-logging operations. The modified drag-chain is designed to be pulled by crawler-tractors in the 30- to 50-horsepower class. The modified drag-chain scarifier was designed to expose mineral soil in spot areas under standing trees. Preliminary tests indicate that the modified chain may distribute seed better than rakes or disks, although rakes and disks may provide better soil disturbance.

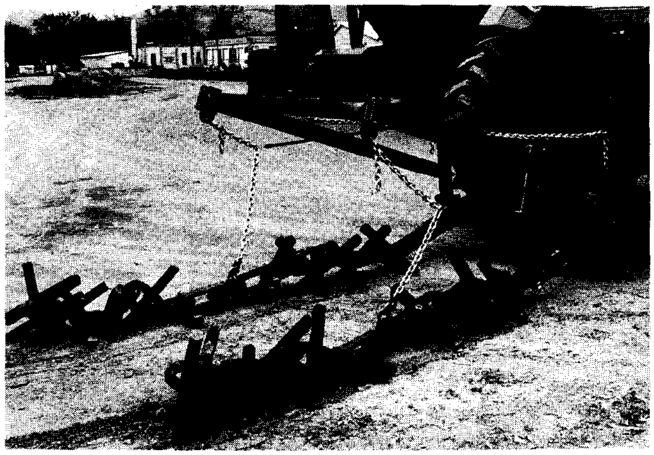

Figure 2—*Modified anchor chain scarifier shown with three-point hitch drawbar and lift attachment.*

The modified drag-chain employs two lengths of lightweight drag-chain instead of the three heavy strands in the original. Two-inch-square bar stock, 24 inches (61 cm) long, welded to each length of chain, increases scarification. Swivels divide the strands to provide a rolling action. Cross bars are 2 x 2 inches (5 x 5 cm) square x 20 inches (50 cm) long. During field tests, 10 links made up a strand that scarified a 6-foot-wide (2-m-wide) swath with about 50% scarification. Links weigh approximately 25 pounds (11 kg) each. The anchor chain scarifier weighs approximately 1,200 pounds (545 kg). The scarifier incorporates a unique spread bar for use with a three-point hitch, which increases maneuverability. Hoist lines suspended from a pair of rigid arms raise and lower the unit.

Crews elected to use a skidder to pull the chain instead of a crawler-tractor during tests. The results were satisfactory. The chain is self-cleaning and rolls over slash downfall better than other implements. Roots of competing grasses are pulled out by the chain. The modified drag-chain scarifier is not recommended for slopes exceeding 30%.

The small drag-chain scarifier costs about $4,000. For additional information on the system, contact:

Dick Karsky USDA Forest Service Missoula
Technology and Development Center Building 1,
Fort Missoula Missoula, MT 59801 (406) 329-3921

Three-Point Hitch-Mounted Disk

Traditionally, standard trailer-mounted towed disks have been used to prepare soil in paper birch stands, but they were prone to overturn on moderate slopes. To ensure stability on slopes up to 35%, a commercially-available three-point hitchmounted disk was attached to a 30- to 50-horsepower crawler-tractor to scarify steep slopes (figure 3). The three-point mount can be used with a variety of commercially available light to heavyduty disks. With the capacity to lift the disk out of the ground in wet spots and other problem areas,

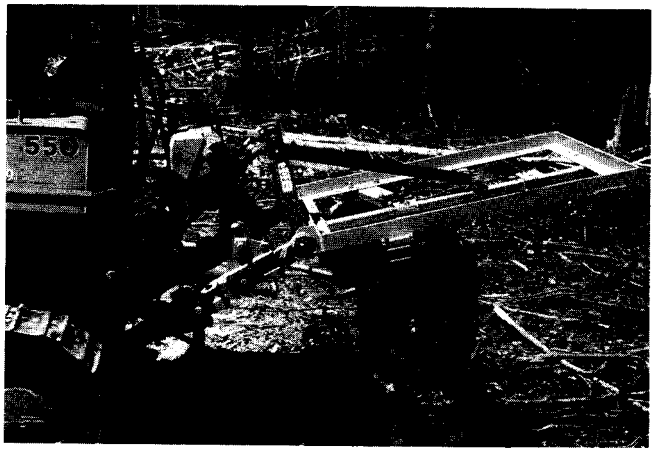

Figure 3—*Three-point hitch and three-point hitch-mounted disk.*

the three-point hitch affords greater tractor maneuverability than the trailer-towed version. Additionally, the hitch-mounted disk can be used with good results in conjunction with a front-mounted Salmon blade.

The disk provides good soil mixing. However, in tests, the three-point hitch-mounted disk, which was a 24-inch (61 cm) lightweight agricultural disk weighing about 700 pounds (318 kg), was not heavy enough to achieve desired soil coverage. A heavy-duty disk weighing 1,500 to 2,000 pounds (680 to 910 kg), with 26-inch (66-cm) disks should be adequate for forest site preparation. The three-point hitch-mounted disk appears to be less effective than the Salmon blade at reducing the invasion of competitive grasses. Use of a three-point hitch attachment on crawlers used for fire plows requires installation and removal of the attachments to vary operations. The three-point hitch-mounted disk can be used successfully when the crawler-tractor is dedicated exclusively to site preparation.

The three-point hitch-mount is available commercially for about $5,000. Standard towed disks range in price between $1,500 and $6,000, depending on the type of application intended. Approximate weight of the mounted disk is 750 to 3,000 pounds (340 to 1,360 kg). For additional information, contact:

Dick Karsky USDA Forest Service Missoula
Technology and Development Center
Building 1, Fort Missoula
Missoula, MT 59801
(406) 329-3921

Tree Planter's Notes Volume 44, No. 1 (1993)

Mobile Tree Seedling Coolers

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Two mobile coolers have successfully protected seedlings from exposure to the elements. The two pickup-sized coolers keep seedlings in a temperature-controlled environment while they are being transported from a centrally located storage area to the planting site. A *third, non-refrigerated Canadian cooler can be useful in areas where the temperatures are around* 50 /F *(10 °C) during planting season.* Tree Planters' Notes 44(1):16-18; 1993.

Two mobile coolers have been evaluated by engineers at the Missoula Technology and Development Center (MTDC) (figure 1). The coolers have successfully protected seedlings from stress caused by exposure to heat and the elements. Seedlings must be kept cool, moist, and near dormancy from the time of lifting, during shipment to the planting site, until they can be planted. The pickup-sized coolers transport seedlings from a centrally located cooler to the planting site and then hold the seedlings at the planting site in a temperature-controlled environment. A fully loaded cooler will weigh between 3,000 and 3,500 pounds (1,361 to 1,586 kg). Coolers hold approximately 25 to 30 boxes of seedlings. The coolers are available commercially.

Polar Products Seedling Cooler

The first prototype cooler was built for MTDC by Polar Products of Torrance, California. Polar Products custom-designed a 12-V dc refrigeration system and installed it in a prebuilt canopy. The canopy was constructed of a hardwood frame with white-painted aluminum sheeting on the exterior and stainless steel sheeting on the interior. The walls were insulated with 3½ inches (8.9 cm) of polyurethane foam. Interior shelving was constructed of perforated metal supports and plywood panels. The 12-V refrigeration system could be operated by a generator on the vehicle engine, a roof-mounted photovoltaic array, or standard 117-V ac through a battery charger.

The refrigerator compressor and condensing components were located in a housing on the front of electronics panel controlled the power source switching and was housed in a weatherproof enclosure on the passenger side of the cab over hang. Refrigeration was provided by a cold plate evaporator, where refrigeration tubes are encased in a solution that freezes at a specific temperature. This type of evaporator is heavier than fin-and-tube evaporators, but the cold plate provides cooling when the refrigeration system is not operating.

Field tests were conducted on the Stanislaus National Forest's Calavaras and Mi-Wok Ranger Districts in the Pacific Southwest Region, on the Siskiyou National Forest's Illinois Valley Ranger District, and the Umatilla National Forest's Walla Walla Ranger District in the Pacific Northwest Region. The cooler performed effectively. In-bag seedling temperatures below 35 /F (1.7 /C) were maintained over the 6-hour period from arrival at the site to the last bag-up. Ambient temperature during the cooler field tests ranged in the mid-50 to 75 /F (12.8 to 23.9 /C) range.

The cooler was also tested at MTDC facilities. Thermocouples and a data logger were used to record air temperatures and cold plate temperature during initial start-up and simulated field conditions. The initial pull-down (the time required to completely freeze the solution in the cold plate upon initial start-up) took about 8 hours. After about 16 hours, the interior air temperatures stabilized and an approximately 2 /F (1.1 /C) temperature differential existed between the top and bottom of the cooler. Temperatures were also recorded under simulated field conditions in 70 /F (21.1 /C) ambient air temperature. The air temperatures inside the cooler increased approximately one degree per hour.

Some users were concerned that the cooler was too heavy and too complicated for their needs. As a result, Polar Products reconstructed the canopy with welded frames of aluminum tubing, which reduced the weight from over 2,000 pounds (907 kg) to 1,800 pounds (816 kg). The refrigeration was changed to operate on 120-V do and could be powered from an additional alternator on the vehicle engine and by a standard electric outlet equip the cooler with an ac-powered refrigeration system if the pickup engine operation feature is not required.

Specifications. This cooler is available at the following address:

Polar Products, Inc.
2808 Oregon Court, Bldg. K-4
Torrance, CA 90503
(310) 320-3514

Construction: Frame, welded aluminum tubing
Insulation: 3½ inch (8.9 cm) polyurethane FIP
Outside dimensions: 82 inches x 82 inches x 96 inches (208 cm x 208 cm x 244 cm)
Refrigeration system: 117-V ac operation; hermetic-type condenser; cold plate evaporator
Weight: Approximately 1,800 pounds (816 kg)
Capacity: 25 to 30 boxes
Estimated cost per unit: 1-5, $14,000; 6-8, $12,000; 10+, $10,000,

Isoloc Seedling Cooler

The second prototype seedling cooler was built for MTDC by Isoloc Manufacturing Company of Vancouver, Washington. Isoloc installed an MTDCdesigned refrigeration system in a custom-built canopy (figure 1). The canopy walls are constructed of 3½ inches (8.9 cm) of polyurethane insulation sandwiched between plywood panels. White-painted, stucco-embossed aluminum sheeting covers the exterior, while aluminum sheeting lines the interior. Interior shelving is constructed of aluminum H-beams and round aluminum tubing.

The refrigeration system operates on 117 V ac. In the field, refrigeration is provided by the cold plate evaporator. The interior air is circulated by a fan operating on 12 V dc. The fan is operated by a 12-V, deep-cycle, RV battery. A trickle-type battery charger is permanently wired into the electrical system to recharge the battery when the cooler is plugged in. The battery charger is equipped with a sensor that turns the charger off when the battery is fully charged.

Figure 1—*Isoloc seedling cooler (**left**) and Polar Products seedling cooler (**right**).*

During testing at MTDC facilities, the initial pull-down of the cold plate evaporator took about 9 hours. The air temperature inside the cooler stabilized in about 18 hours. After the air temperatures stabilized, a 25 °F (13.9 °C) temperature gradient existed between the top and bottom of the cooler.

The cooler was tested on the Lolo National Forest's Superior Ranger District in the Northern Region and on the Malheur National Forest's Bear Valley and Long Creek Ranger Districts in the Pacific Northwest Region. In-bag seedling temperatures were about 40 °F (4.4 °C) when placed in the cooler and in-bag seedling temperatures lowered 3 to 6 degrees F (1.6 to 3.3 degrees C) during 8 hours of storage at the planting site. On one occasion, the seedling temperature reached 31.5 °F (-.3 °C) and the cooler door was left open to prevent the seedlings from freezing. The ambient air temperature on that day reached a high of only 52 °F (11.1 °C).

The ac refrigeration system was simple and convenient to operate. The cooler provided adequate cooling to meet the field users needs.

Specifications. This cooler is available at the following address:

Isoloc Manufacturing Company
PO Box 61522
Vancouver, WA 98666
(206) 695-3230

Construction: Wood frame
Insulation: 3 inches (7.6 cm) urethane
Outside dimensions: 96 inches long x 84 inches wide x 79 inches tall (244 cm x 213 cm x 201 cm)
Refrigeration system: 117-V ac operation; 1 hp Copeland Condensing Unit; Dole Truk-Cel Evaporator Unit
Weight: Approximately 2,000 pounds (907 kg)
Estimated cost: $11,500

Canadian Cooler

A third cooler has been identified that may be useful to nursery managers (figure 2). Horizon Fiberglass Products, Ltd., Delta, BC, Canada, has an insulated, non-refrigerated cooler that may be sufficient in areas where ambient high temperatures are in the low 50 /F (10 /C) range during planting season.

The interior and exterior walls are made of molded fiberglass-reinforced plastic and are covered with a clear gel coating. The bottom of the canopy is not molded to fit a particular make of pickup, which allows it to slide into any standard American pickup-bed with an 8-foot box. The walls have 1 ½ inches (3.8 cm) of phenolic foam insulation.

The inside shelving consists of metal supports an plywood seedlings below 50 /F (10 /C). A roof-mounted ventilator allows warm air near the top of the cooler to escape. In tests conducted by the Forest Engineering Research Institute of Canada, air temperatures within the canopy ranged from 45 to 54 /F (7.2 to 12.2 /C) in ambient air temperatures that ranged from 41 to 72 /F (5 to 22 /C). The cooler weighs 450 pounds (204 kg) and is distributed by International Reforestation Suppliers of Eugene, Oregon.

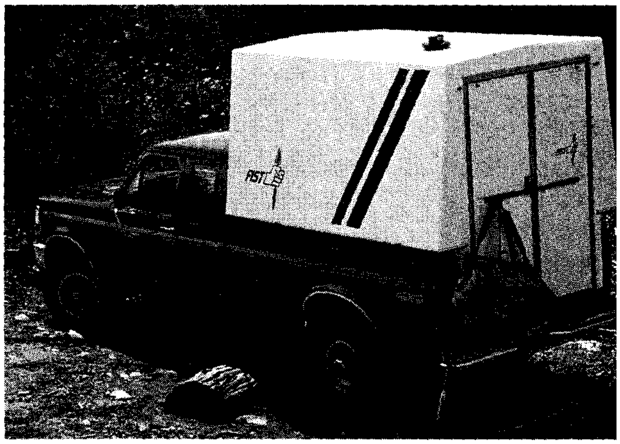

Figure 2—*Canadian non-refrigerated cooler.*

Specifications. This cooler can be obtained from the following suppliers:

Horizon Fiberglass Products, Ltd.

3551 River Road West
Delta, BC, Canada V7K 3N2
(604) 946-8718

International Reforestation Suppliers
2100 West Broadway
PO Box 5547
Eugene, OR 97405
(503) 345-0597

Construction: Molded fiberglass
Insulation: 3-inch urethane
Outside dimensions: 102 inches long x 75 inches wide x 78 inches tall (259 cm x 191 cm x 198 cm)
Refrigeration system: No refrigeration; roof mounted ventilator
Weight: Approximately 450 pounds (204 kg)
Estimated cost: $4,200 Canadian; $4,380 U.S. FOB Blame, Washington

A report documenting the project is available from

USDA Forest Service
Missoula Technology and Development Center
Building 1, Fort Missoula
Missoula, MT 59801

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Germination Math: Calculating the Number of Seeds Necessary per Cavity for a Given Number of Live Seedlings

Maria Schwartz

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The hand-held calculator can be an indispensable tool in calculating the number of seeds to sow in a container to optimize seed use. By entering the germination failure rate, then keystroking universal power (Y^X), *keystroking the number of seeds expected to be sown per cell, keystroking equals, almost any hand-held calculator can display quickly and accurately the decimal expression of empty cells occurring. Scenarios derived through the use of this simple mathematical calculation can show growers how to get a maximum number of germinates from a finite number of seeds.* Tree Planters' Notes 44(1):19-20; 1993.

Planting a seed is basically an exercise in what can be called binomial probability. A seed either grows or it doesn't. Those are the only two conditions that can occur. Knowing this allows us to calculate the probability of various numbers of seeds germinating when sown in containers. The basis for these calculations is the **binomial expansion.**

Binomial expansions for several sowing conditions are presented below, where X equals the probability of a seed germinating and Y equals the probability of a seed failing to germinate.

$$(X + Y)^2 = X^2 + 2XY + Y^2$$

illustrates the conditions that can occur after 2 seeds have been sown. X^2 is the probability of both seeds germinating, 2XY is the probability of 1 seed germinating and the other failing to germinate, and Y^2 is the condition where both seeds fail to germinate.

$$(X + Y)^3 = X^3 + 3X^2Y + 3XY^2 + Y^3$$

represents the conditions that can occur when 3 seeds are planted.

$$(X + Y)^4 = X^4 + 4X^3Y + 6X^2Y^2 + 4XY^3 + Y^4$$

represents the conditions that can occur when 4 seeds are planted.

$$(X + Y)^5 = X^s + 5X^4Y + 10X^3Y^2 + 10X^2Y^3$$

$$+ 5XY^4 + Y^5$$

is the mathematical expression of the conditions that can occur when 5 seeds are sown.

Consider the case $(X + Y)^4$. The exponent 4 indicates that 4 seeds were planted.

X^4 indicates the probability of all 4 seeds germinating.

$4X^3Y$ indicates the probability of only 3 seeds germinating and 1 seed failing to germinate.

$6X^2Y^2$ is the probability of 2 seeds germinating and 2 seeds failing to germinate.

$4XY^3$ is the probability of 1 seed germinating and 3 seeds failing to germinate.

All of the above conditions amount to about the same thing, a living seedling in the cell. The condition that concerns us most is the last.

Y^4 is the failure of all 4 seeds to germinate-an empty cell or container with no seedling.

Knowing this allows us to quickly calculate the probability of empty cells, given the number of seeds sown, if we know the germination rate of the seed we are sowing. A hand-held calculator makes this as easy as falling off a log! (Math humor and tree humor at the same time?)

To calculate the number of seeds necessary per cavity to achieve a given number of live seedlings, raise the decimal expression of the percentage germination failure rate to the seeds per cell power.

Any hand-held calculator with a universal power key (figure 1) can be used. Here's what I do: first, key-in the decimal representation of the germination failure rate, then key-in Y^X, key-in number of seeds I might sow, and finally, key in equals.

Try this example: A seed lot has 95% germination, that is 95% of the seeds grow, 5% don't. This is a failure rate of .05. If I plant 1 seed per cavity I would calculate .05 raised to the 1 power = .05 or 5% blanks.

Now try 2 seeds: .05 raised to the 2 (second) power is $.05^2 = .0025$. Only .25% blanks, less than one per hundred.

A second way to look at this example is the first 100 seeds will produce 95 seedlings; sowing an additional hundred seeds in the same cells will yield only 4 to 5 more seedlings. In my judgment, that is not a very wise use of seed.

Now try a seed lot with 78% germination, that is a 22% failure rate. For 1 seed per cell, calculate .22 to the first power: 22% empty cells. For 2 seeds per cell, calculate .22 to the second power: .0484 = 4.84% empty cells. How about 2½ seeds per cell? Calculate $.22^{25} = .0227$ = 2.3% empty cells.

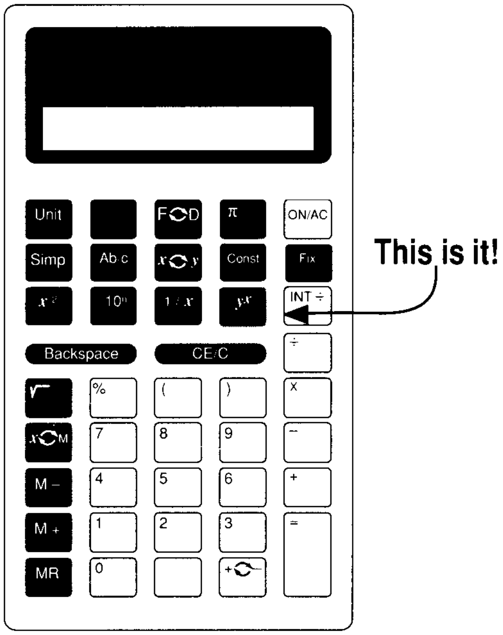

Figure 1—*Calculator with universal power key (^, exp, Y^X, or X^y) indicated.*

For 3 seeds per cell, calculate .22 to the third power: .010648 = 1% empty cells.

Another way to look at this example is that the first hundred seeds yield 78 seedlings, the second hundred seeds yield 17 more trees, and the last hundred seeds used yield only 4 more trees. So now we are faced with the following questions:

! Should I plant four seeds per cell to get a rate of .22 to the fourth, or .0023 = .2%, less than 1% empty cells?
! Would it be worth 100 seeds to get one more tree?
! For that matter, was it worth 100 seeds to get 4 more trees, the difference between 2 and 3 seeds per cell?
! Should I drop back to 2 seeds per cell, have less thinning, and only get about 5 blanks per hundred cells?
! How much did this seed cost?
! How much seedborne disease is in this stuff?
! How long do I want to run this seeder?
! How reliable are the germination data anyway?

I don't know the answers to any of these questions. But now I hope you know how to calculate the number of expected empty cells depending on seed germination and number of seeds sown.

Short Cut or Guess and Check

1. **Enter the % germination failure.**
2. **Enter exponent (common symbols for this universal power key are ^ *(the carat symbol) exp*, Y^X, X^Y)**
3. **Enter how many seeds you want to sow per cell.**
4. **Enter equals (=). If this rate is close to acceptable, do it!**

If a calculator lacks the capability to raise a number to a variable power, just use repeated multiplication, for whole number amounts. For example: .22 germination failure, 3 seeds per cell.

$$.22 \times .22 \times .22 = .010648$$

Only 1% empty cells.

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Germination of Alaska-Cedar Seed

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Seeds of Alaska-cedar (Chamaecyparis nootkatensis *D. Don) were tested for germination following combinations of warm and cold stratification. For nursery sowing, good germination can be achieved using 60 days of warm stratification followed by 90 days of cold stratification. Extending stratification periods beyond these times may result in seed loss from seed germination during stratification and from seed molds. Unstratified seed sown in greenhouses in late summer will germinate well the following spring if greenhouse temperatures are lowered during fall and winter to meet cold stratification requirements.* Tree Planters' Notes 44(1):21-24; 1993.

Alaska-cedar *(Chamaecyparis nootkatensis* D. Don) occurs from Prince William Sound in Alaska to the mountains of Oregon and northwestern California (Viereck and Little 1972). Alaska-cedar reaches its best development on the islands of southeast Alaska and in British Columbia, where it is also known as yellow-cedar or yellow cypress.

The wood is highly valued because it is resistant to attack by insects and decay fungi. It has been used for boat construction, decking, window framing, and other construction uses where the wood is exposed to the weather. Native Americans have used the wood and bark for many purposes and continue to use the wood for carving and bark for weaving.

In southeast Alaska, the best development of Alaska-cedar occurs on moderately productive sites at elevations of 150 to 475 m (500 to 1,500 feet). It is also found on poorly drained or on shallow sites with low productivity. On more favorable sites it is unable to compete with western hemlock. *(Tsuga heterophylla* (Raf.) Sarg.), Sitka Spruce *(Picea sitchensis* (Bong.) Carr.), and western redcedar *(Thuja plicata* Donn.). Timber harvest in southeast Alaska over the last 30 years was concentrated in high-volume, low-elevation stands, generally with a low Alaska-cedar component. With the designation of wilderness and more complex land-use designation patterns, timber harvest now occurs in a variety of stands. These changes, and greater demand for Alaska-cedar wood, have resulted in increased harvest of stands where Alaska-cedar is a major component.

Regeneration requirements of Alaska-cedar are poorly understood. Seedlings are uncommon in the understory and on regeneration sites following logging of stands that previously contained Alaska cedar. If Alaska-cedar is to be a component of second-growth stands, artificial regeneration will be required on many sites.

Alaska-cedar seeds are difficult to germinate. Germination is usually poor and may be delayed for up to a year. Seeds sown in the spring may not germinate until the following year. Stratification recommendations for Alaska-cedar seeds are poorly developed. Bensen (1969) achieved 10% germination using a 58-day warm period followed by a 30-day cold period. Harris (1974) summarized early germination test and results of nursery sowings and suggested other variations of warm periods followed by cold periods might be needed to optimize germination.

Our earliest attempt to grow Alaska-cedar at the B. F. Heintzleman Nursery at Petersburg followed a November 1983 seed collection. Although initial germination was low, seeds germinated well the following spring after a winter at temperatures above freezing (average minimum daily temperature). We found that seed viability was good and that seedlings could be produced if stratification requirements were met.

Because experience with nursery sowing suggested that seed germination could be increased with extended warm stratification followed by cold stratification, and since similar results were reported for other nursery sowings (Harris 1974), this study was initiated to test the effect of various combinations of warm and cold stratification treatments on seed germination of Alaska-cedar.

Methods

In October 1985, Alaska-cedar cones were collected from 25 to 30 trees at an elevation of 335 to 365 m (1,100 to 1,200 feet) on Mitkof Island in southeast Alaska. Seeds were extracted from the cones and stored at -18 /C (0 /F). After 2 weeks, the seeds were removed from storage and warmed to room temperature. Then, the seeds were placed in a polyethelene bag and soaked in water for 24 hours. Excess water was drained from the bag and the seeds were put into warm stratification.

For warm stratification, seeds were placed in a room where temperatures fluctuated between 13 to 24 /C (55 to 75 /F). At the start of warm stratification (0 days), and at 30-day intervals from 30 to 240 days, samples of the seeds in warm stratification were transferred to separate polyethelene bags and placed into cold stratification at 1 to 2 /C (34 to 36 /F). For each sample, germination was tested for the seeds at 30-day intervals in cold stratification from 30 to 240 days. Thus, there were 72 treatment combinations-nine levels of warm stratification, each with eight levels of cold stratification.

Seeds removed from cold stratification at the appropriate times for testing were placed onto moist potting soil in covered plastic trays. Each treatment was replicated three times, using 100 seeds per-replication. Trays containing seeds were placed in an incubator at 24 /C (75 /F). The trays were examined every 2 or 3 days and the number of germinated seeds was recorded. Seeds were considered to have germinated when the seed coat lifted above the soil. Germinated seeds were removed from the trays as they were counted and the test ended after 28 days.

The study was installed as a randomized complete block experiment with three replications. Because all treatments were not be tested at the same time, one replication of each treatment was assigned to each of three levels in the germination chamber. Location of each treatment within a repcations was assigned randomly to one of nine locations, the maximum number of treatments being evaluated at any time. Data were subjected to an analysis of variance. Main affects were compared using Duncan's multiple range test at the 0.05 level of significance (Snedecor and Cochran 1967).

In addition to these laboratory tests, starting in November 1985, a 4-cubic-inch Styroblock with 240 cavities was sown each month for a year (until October 1986) with unstratified seed taken from cold storage. Sown Styroblocks were placed in a production greenhouse to test whether greenhouse conditions could meet stratification requirements for Alaska-cedar seeds. This portion of the study was not replicated. From August 1986 through November 1986, greenhouse temperatures varied with outside temperatures. No heat was added, but temperatures were kept below 27 /C (80 /F) on sunny days. From December 1986 through February 1987, temperatures were kept above freezing but not allowed to exceed 7 /C (45 /F). By March, seedlings grown for reforestation were lifted and temperatures in the greenhouse were kept above freezing but allowed to rise during the day. Temperatures in the greenhouse were kept at 24 /C (75 /F) during the first 3 weeks of April 1987. After that, day temperatures were maintained at 24 to 27 /C (75 to 80 /F) and allowed to cool to 13 /C (55 /F) at night. The percentage of seed germinating in the greenhouse was scored on March 1, 1987, before greenhouse temperatures had begun to rise and again on March 21, 1987, after 3 weeks of warm temperatures that favored germination.

Results

Laboratory germination. Germination of seeds following stratification was affected by the length of time in warm and cold stratification (table 1). Warm stratification for 30 to 150 days significantly increased germination over that of untreated seeds. Germination over all cold treatments was highest, about 58%, with warm treatments of 60 to 120 days, after which germination percentages decreased due to mold development on the seeds. After 150 days in warm stratification, no seed germinated regardless of cold stratification treatment.

Length of cold stratification increased germination percentages through 90 days for all levels of warm stratification (table 1). After 90 days of cold stratification, germination percentages decreased as length of cold stratification increased. This decrease can be explained, to some extent, by the onset of seed germination during cold stratification when cold stratification was in excess of 90 days. Even though those germinated seeds were excluded mathematically from the calculation of germination percentage during the germination phase, removal of seeds that germinated during stratification reduced the number of seeds with germination potential in the test samples. This resulted in germination percentages being lower than would have occurred had the seeds not germinated in stratification. The highest numerical germination was 69% for the treatment with 60-day warm stratification followed by 90-day cold stratification; with no warm stratification, germination percentages increased with increased cold stratification. Also, at

Table 1 *-Germination of Alaska-cedar seed after 30 to 240 days of warm stratification followed by 30 to 240 days of cold stratification**

	Percent germination								
Days warm stratification	30 days cold	60 days cold	90 days cold	120 days cold	150 days cold	180 days cold	210 days cold	240 days cold	Mean warm days
0	0	1	0	0	1	4	6	10	3 a
30	16	52	66	57	52	47	53	28	47 c
60	37	64	69	68	67	60	54	55	59 e
90	49	61	68	65	57	50	60	56	58 e
120	48	57	61	60	62	58	52	52	56 d
150	11	11	15	13	11	12	13	12	12 b
Mean cold days	27 a	41 cd	47 f	44 a	42 d	28 a	40 c	34 b	

Means within columns followed by a common letter are not significantly different. Means within rows followed by a common letter are not significantly different ($P < 0.05$).

*Seeds germinating during stratification are not included.

150 days of warm stratification, there were only small differences in germination at any level of cold stratification (range, 11 to 15%).

Greenhouse germination. Seeds sown monthly from November 1985 to October 1986 into Styroblocks and placed into the greenhouse germinated poorly through March 1, 1987 (table 2). Germination was somewhat higher with the earlier sowings but did not exceed 10% (for example, January 1986). No germination occurred in sowing after July 1986. During the months of December 1986 through February 1987, greenhouse temperatures were too low for germination. After March 1, 1987, greenhouse temperatures increased and ungerminated seeds began to germinate. Germination continued through March 21, 1987, when seedlings and recent germinants were counted. Highest germination was 83% for the September 1986 sowing and lowest (17%) for the March 1986 sowing. Germination for the other sowings ranged from 31 to 67%.

Table *2-Greenhouse germination of unstratified Alaska-cedar seed sown monthly from November 1985 to October 1986*

	Percent germination	
Date sown	March 1, 1987	March 21, 1987
November 85	4	57
December 85	6	51
January 86	10	34
February 86	4	32
March 86	5	17
April 86	9	52
May 86	2	47
June 86	4	62
July 86	1	55
August 86	0	67
September 86	0	83
October 86	0	31

Germination percentages for March 1, 1987, show the germination that occurred without a warm stratification period followed by a cold stratification period. By March 1, 1987, stratification requirements were met but greenhouse temperatures were too low for seed germination. With increased greenhouse temperatures after March 1, stratified seed germinated through March 21, 1987.

Discussion

Germination of Alaska-cedar seeds requires a period of warm stratification followed by a period of cold stratification for a high percentage of the seeds to germinate. Seeds with no warm stratification germinated poorly even after 240 days of cold stratification. Some seeds with extended warm stratification and no cold stratification will germinate. However, warm stratification of more that 120 days' duration can result in loss of seed viability due to storage mold.

Monthly sowing of unstratified seed in the semi-operational greenhouse trial gave results similar to those from the controlled germination study. Seed germination was delayed in the greenhouse until both warm and cold stratification requirements were met, at least 60 days of warm stratification followed by 90 days of cold stratification (table 2). The September 1986 sowing produced the highest level of germination. Most likely, seed germination in the earliest sowing-November 1985 through February 1986-was delayed for over a year until these requirements were met. The low germination rate for the March 1986 sowing and the variation in germination among sowing dates may be due, in part, to dislodging of seeds from the containers by irrigation spray. The main finding of the greenhouse germination study is that with temperature modifications, Alaska-cedar seeds can germinate at similar levels as in the laboratory.

Conclusions

Nursery managers growing Alaska-cedar seedlings must use stratified seed to ensure good germination. Seed can be sown in late summer and placed into greenhouses where warm and cold stratification requirements will be met, or they can be sown in spring with stratified seed. Good results can be expected with 60 days of warm stratification followed by 90 days of cold stratification. Some variation in the warm stratification period around 60 days should not greatly affect germination as long as the cold stratification period is at least 90 days. Seeds held in warm stratification beyond 90 days may begin to germinate in stratification and seeds held beyond 120 days may begin to mold.

The poor success in regenerating Alaska-cedar in second growth stands in southeast Alaska can be explained in part by its seed characteristics. Seed production of Alaska-cedar is never abundant when compared to Sitka spruce, western hemlock, and western redcedar, its chief associates. Seeds from these species require little or no stratification for germination, giving them an advantage in quickly occupying sites following logging. Only a small percentage of Alaska-cedar seed will germinate the first year after seed dispersal. The remainder of the seeds will need another year to meet their stratification requirements. During this time, the seed numbers may be consumed by birds and rodents or killed by fungi. Until methods are developed to ensure adequate natural regeneration, artificial regeneration will be required if Alaska-cedar is to be well represented in second-growth stands in south east Alaska.

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Acknowledgments

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First-Year Survival and Growth of Loblolly Pine Seedlings Released From Perennial Weeds in Old Fields of Northeastern Arkansas

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Selected herbicide mixtures were assessed for controlling perennial weeds in old pastures and enhancing the growth of recently planted loblolly pine (Pinus taeda L.). *Bareroot seedlings planted in February 1990 near Batesville, Arkansas, were released from herbaceous perennial weeds with herbicides in April 1990. After one growing season, seedling mortality was 18% in treated and 30% in untreated plots. Seedling height was less responsive to weed control than diameter, with both attributes less responsive than expected, possibly because soils were compacted from previous land uses. Most herbicide mixtures studied offered similar weed control, pine tolerance, and seedling growth. Relative stem biomass per dollar of herbicide was greatest for sulfometuron + hexazinone (0.04 + 0.22 kg active ingredient per treated hectare).* Tree Planters' Notes 44(1):25-32; 1993.

Privately owned hardwood forests, primarily of the oak-hickory type, are predominant in the Ozark region of Arkansas (Hines 1988). Since 1978, there has been a 10% increase in timberland acreage in this region, with at least 95% of this increase from pasture and cropland conversion (Hives 1988). Planting old fields with loblolly pine *(Pinus taeda* L.) is attractive because it is a fast-growing, high-quality species whose planting is often cost-shared through Federal programs such as the Forestry Incentive, Conservation Reserve, and Stewardship Incentive Programs.

Most research documenting the negative impacts of herbaceous competition has involved previously forested coastal plain sites that were prepared for planting. Herbicide treatments commonly used on these sites may not be adequate when establishing pine on old-field sites in northeastern Arkansas. Sulfometuron (Oust®) and sulfometuron + hexazinone (Velpar® L) are commonly used in young pine plantations (Cantrell et al. 1985). These are effective herbicides, but other herbicide mixes show promise for controlling herbaceous weeds. Recent work on old-field sites in Georgia and South Carolina indicated that sulfometuron + imazapyr (Arsenal® AC) can effectively repress johnsongrass *(Sorghum halepense* (L.) Pers.) and bermudagrass *(Cynodon dactylon* (L.) Pers.) (Edwards and Dougherty 1988, Edwards et al. 1990, Nelson and Franklin 1990), but efficacy has not been documented for many common perennial weeds in Arkansas.

Data documenting pine response to control of perennial weeds for old-field sites within northeastern Arkansas are limited. Furthermore, herbaceous weed control efficacy and the resulting pine growth and biomass production following application of tank mixes containing combinations of sulfometuron, hexazinone, and imazapyr have not been studied. Consequently, a study was established on an old field in northeastern Arkansas to assess the potential of selected herbicide treatments for (1) pine seedling injury and growth resulting from individual applications of herbicides (index treatments); (2) controlling unwanted perennial weeds common to old pastures; and (3) enhancing the growth of newly planted loblolly pine seedlings by release from competition with selected operational tank mixes.

Methods

Study site. The study was established on an old-field site in the Ozark Mountains on the Livestock and Forestry Branch of the Arkansas Agricultural Experiment Station, near Batesville in Independence County. This site typifies old fields located in northern Arkansas that are candidates for conversion to forest. The soil was a Gepp very cherty silt loam, well drained and low in natural fertility (Ferguson et al. 1982). Rattail fescue *(Vulpia myuros* (L.) C. Gmelin), a perennial grass, and goldenrod *(Solidago* spp.*),* a perennial broadleaf weed, were visually assessed prior to treatment as evenly distributed across all plots and suitable for testing. Other plants growing in the field but not suitable for testing were winged (also shining or dwarf) sumac *(Rhus copallina* L.), broomsedge, foxtail grass *(Setaria* spp.*),* miscellaneous sedges *(Carex* spp.*)* and beaked panicgrass *(Panicum anceps* Michaux).

Loblolly seedlings were hand-planted in February 1990 on a 1.8 x 3.6 m spacing. The planting stock was genetically improved first-generation seed orchard, 1+0 bareroot seedlings obtained from the Arkansas Forestry Commission's Baucum Nursery in Little Rock. At the time of herbicide application late in April 1990, fescue was 15 to 20 cm tall, goldenrod was 20 to 25 cm tall, and pine seedlings averaged 25.9 cm tall and had recently flushed 1.27 cm.

Study layout. The study was established as a randomized complete block with 3 blocks and 12 treatments per block. Plots were 1.2 x 33 m, surrounded by 1.2-m buffers, and centered over 18 loblolly pine seedlings spaced evenly at 1.8-m intervals throughout the plot.

Of the 12 treatments, 1 was an untreated control, 4 were index treatments, and 7 were operational treatments. Index treatments received single applications of one herbicide in April 1990 followed by additional applications in June and August 1990 of 3% glyphosate (Roundup®) in water solution (table 1). Seedlings in index plots were shielded from the glyphosate spray to prevent death or injury to actively growing pine seedlings (Cantrell et al. 1985). Weeds growing at the base of seedlings were removed by hand. The seven operational treatments received a one-time application of herbicide in April 1990 (table 1). A single herbicide application is typical of weed control practiced in young loblolly pine stands (Minogue et al. 1991). Herbicide applications were made over the top of seedlings at 140.3 liters/ha (15 gallons per acre) with a 2-nozzle, hand-held spray boom equipped with flat-fan nozzle tips.

Untreated control plots show the impact of herbaceous competition on seedling survival and growth. In contrast, total vegetation control achieved with the index treatments illustrates the growth and seedling injury resulting from herbicide treatments without the confounding effects of competition, thus enabling us to determine whether growth inhibitions were significant. Operational treatments allow determination of the growth reweed control provided by each of the tank mixes studied.

Evaluations. Control of fescue and goldenrod, percentage bare ground, and pine seedling injury were recorded 60 and 120 days after treatment (DAT) in each plot relative to the untreated check. Control of fescue and goldenrod plus bare ground estimates were visually ranked in 10% classes, with 0% indicating no control and 100% total control. Percentage bare ground was an estimation of plot area not covered by live herbaceous plants. Pine seedling injury was evaluated in 10% classes so that 0% indicated a healthy seedling with terminal elongation, 30% a stunted seedling, 50% a completely chlorotic seedling, and 100% a dead seedling.

Initial stem height (centimeters) and diameter (centimeters) were measured in February 1990, immediately after planting. First-year stem height, diameter, and survival were recorded on all seed lings in early December 1990. Seedling height was measured with a ruler from groundline to the apex of the terminal bud, and stem diameter was measured with vernier calipers at groundline.

In early December 1990, all surviving pines were carefully dug from the ground. Seedlings were brought back to the laboratory where they were washed free of soil and dissected into roots, needles, stems, and branches. These biomass components were ovendried and their weights measured on a balance scale to the nearest 0.01 g.

Data analysis. Before analysis, percentage values for fescue and goldenrod control, bare ground, pine injury, and seedling survival were transformed with $\arcsin\sqrt{\%}$ (Steel and Torrie 1980). A stem biomass /herbicide cost ratio was developed to assess wood fiber gains over herbicide cost per hectare-weight of stem biomass component (kilograms per hectare) /herbicide cost (dollars per hectare). Analysis of variance was used to test data (SAS Institute 1988), and means were separated with Tukey's studentized range test (a = 0.05). Untransformed values are presented in this paper.

Results and Discussion

Visual plot evaluations. Control of perennial weeds and percentage bare ground were comparable among operational treatments (table 2). Goldenrod was easily controlled by operational treatments averaging 91% 60 DAT and 85% 120

Table 1 -*Herbicide treatments for perennial weed control applied in late April 1990 near Batesville, Arkansas*

Herbicide treatment	Application rate*					
	Sulfometuron		Imazapyr		Hexazinone	
	ai	product	ai	product	ai	product
Untreated control	-	-	-	-	-	-
Index†						
Sulfometuron	0.08	0.15	-	-	-	-
Hexazinone	-	-	-	-	0.67	3.50
Imazapyr	-	-	0.168	0.44	-	-
Imazapyr	-	-	0.279	0.73	-	-
Operational‡						
Sulfometuron + imazapyr	0.04	0.07	0.112	0.29	-	-
Sulfometuron + imazapyr	0.08	0.15	0.056	0.15	-	-
Sulfometuron + imazapyr	0.08	0.15	0.112	0.29	-	-
Sulfometuron + imazapyr + hexazinone	0.04	0.07	0.056	0.15	0.22	1.17
Sulfometuron + hexazinone	0.04	0.07	-	-	0.22	1.17
Sulfometuron + hexazinone	0.08	0.15	-	-	0.45	2.34
Imazapyr	-	-	0.168	-	-	-

*ai = kilograms of active ingredient per hectare (kg ai/ha); product = liters of product per treated hectare (I/ha). [To convert kilograms ai per hectare to pounds ai per acre, multiply by 1.12. To convert liters per hectare to ounces per acre, multiply by 13.7.] All herbicide treatments were mixed with water and applied at 140.3 I/ha (15 gallons per acre).

†Total vegetation control was maintained with subsequent directed applications of a 3% solution of glyphosate in water at 60 and 120 days after treatment.

‡Single over-the-top application of herbicide.

averaged 85% 60 DAT and decreased to 68% 120 DAT. Also, percentage bare ground 60 DAT averaged 88% and decreased to 53% 120 DAT. As expected, index treatments effectively controlled herbaceous competitors throughout the duration of the study with goldenrod control, fescue control, and bare ground averaging 97% 120 DAT.

Based on evaluation of index treatments, individual herbicides did not substantially injure seedlings either 60 or 120 DAT. The greatest seedling injury (22%) was observed with imazapyr (0.279), which showed double the seedling injury of imazapyr (0.168) at 120 DAT (table 2). For operational treatments, seedling injury 60 DAT averaged 6% and was greatest in plots treated with sulfometuron + hexazinone (0.08 + 0.45) (table 2). Seedling injury 120 DAT was 26% for sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22) and was 22% for sulfometuron + hexazinone (0.08 + 0.45) (table 2). Hexazinone is soil active, labeled for use at the rates studied, and has demonstrated its safety when used to release pine seedlings from perennial grasses in pastures in the coastal plain of southwestern Arkansas (Yeiser and Boyd 1989). The unexpected damage may be related to the fact that 0.45 kg ai/ha is at the upper end of labeled rates and that a recent flush provided soft, juvenile tissue, which is highly susceptible to injury. Greater injury resulted from the three-way mixture of sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22) versus either rate of sulfometuron + hexazinone alone. This, in conjunction with injury observed for the individual herbicides, indicates that the mixture of sulfometuron + imazapyr + hexazinone was antagonistic to seedling development.

Pine mortality and growth. Pine seedling mortality averaged 19% across plots receiving an operational herbicide treatment, 16.5% for index treatments, and 30% on control plots (table 3). Greatest mortality on an operationally treated plot resulted from application of sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22). This same mixture also showed the greatest visual injury to seedlings (tables 2 and 3). Least mortality occurred on the index plot treated with imazapyr (0.168) and although all treated plots showed greater survival than the untreated check, this was the only treatment with statistically greater survival (table 3).

Only the sulfometuron (0.08) index treatment produced seedlings with significantly greater heights than the controls (table 3). Greatest total height for operational treatments occurred on plots treated with sulfometuron + hexazinone (0.04 + 0.22, 0.08 + 0.45), both of which exceeded control heights by more than 5 cm. Sulfometuron + imazapyr (0.04 + 0.112) plots showed height growth

Table 2-*Visual evaluations of percentage control of goldenrod and fescue, percentage bare ground, and percentage pine injury 60 and 120 days after treatment (DAT) in late April 1990 near Batesville, Arkansas*

	Percent reduction			
Herbicide treatment (kg ai/ha)	Goldenrod	Fescue	Bare Ground	Injury
60 days after treatment				
Index*				
Sulfometuron (0.08)	98 a	98 a	98 a	8 ab
Hexazinone (0.67)	98 a	98 a	98 a	16 a
Imazapyr (0.168)	98 a	98 a	98 a	2 b
Imazapyr (0.279)	98 a	98 a	98 a	8 ab
Mean	98	98	98	9
Operational†				
Sulfometuron + hexazinone (0.04 + 0.22)	87 b	73 b	77 b	7 ab
Sulfometuron + imazapyr (0.04 + 0.112)	92 ab	90 ab	90 ab	7 ab
Sulfometuron + hexazinone (0.08 + 0.45)	93 ab	90 ab	90 ab	11 a
Sulfometuron + imazapyr (0.08 + 0.056)	92 ab	88 ab	90 ab	2 b
Sulfometuron + imazapyr (0.08 + 0.112)	98 a	95 ab	90 ab	8 ab
Sulf + imaz + hex (0.04 + 0.056 + 0.22)	92 ab	73 b	87 ab	6 ab
Imazapyr (0.168)	88 ab	83 b	90 ab	2 b
Mean	91	85	88	6
120 days after treatment				
Index*				
Sulfometuron (0.08)	97 a	97 a	97 a	15 ab
Hexazinone (0.67)	98 a	97 a	98 a	18 ab
Imazapyr (0.168)	97 a	97 a	97 a	11 b
Imazapyr (0.279)	97 a	97 a	97 a	22 ab
Mean	97	97	97	16
Operational†				
Sulfometuron + hexazinone (0.04 + 0.22)	80 c	57 c	43 c	18 ab
Sulfometuron + imazapyr (0.04 + 0.112)	92 abc	70 b	53 b	18 ab
Sulfometuron + hexazinone (0.08 + 0.45)	80 c	73 b	60 b	22 ab
Sulfometuron + imazapyr (0.08 + 0.056)	83 bc	67 bc	47 bc	15 ab
Sulfometuron + imazapyr (0.08 + 0.112)	87 abc	77 ab	68 ab	18 ab
Sulf + imaz + hex (0.04 + 0.056 + 0.22)	83 bc	63 bc	43 c	26 a
Imazapyr(0.168)	90 abc	67 bc	57 b	15 ab
Mean	85	68	53	19

See table 1 for conversion of kilograms ai per hectare to pounds ai per acre. Means in a column sharing the same letter do not differ significantly (Tukey's studentized range test, " = 0.05).

*Index treatments. Total vegetation control was maintained in these plots with subsequent directed applications of a 3% glyphosate in water solution at 60 and 120 days after treatment.

†Single over-the-top application of herbicide.

approximately 4 cm greater than controls (table 3). Among index treatments, those seedlings treated with imazapyr (0.279) were nearly 4 cm shorter than control seedlings and imazapyr (0.168) seedlings did not substantially exceed heights observed for control plots (table 3).

Groundline diameter was significantly greater than control seedlings for all treatments except sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22) (table 3). Among operational treatments, diameter was greatest for seedlings receiving sulfometuron + imazapyr (0.08 + 0.056) and sulfometuron + hexazinone (0.08 + 0.112), although diameter growth did not substantially differ among operational treatments (table 3). Imazapyr (0.279) showed the least and sulfometuron (0.08) the greatest diameter growth among index treatments, though diameter growth was not substantially different among index treatments (table 3).

Although statistical significance is lacking for height data, height results appear to be biologically pertinent. When height is examined relative to the controls, it is clear that most tank mixes studied had a positive impact on early growth of loblolly seedlings. Lack of statistical significance is probably the result of lack of precision in the experiment due in part to underestimation of the sample size appropriate for the site.

Examination of the index treatment data revealed that the individual herbicides, with the possible ex-

Table 3-*Mortality, total height, and groundline diameter of pine seedlings one growing season after treatment for perennial herbaceous weeds near Batesville Arkansas.*

Herbicide treatment (kg ai/ha)	Mortality (%)	Height (cm)	Diameter (cm)
Initial			
First year	0	20.09	0.36
Index*			
Sulfometuron (0.08)	15 ab	49.53 a	0.99 a
Hexazinone (0.67)	18 ab	41.76 abc	0.81 ab
Imazapyr (0.168)	11 a	38.68 bc	0.84 ab
Imazapyr (0.279)	22 ab	34.70 c	0.76 b
Mean	16.5	41.17	0.86
Operational†			
Sulfometuron + hexazinone (0.04 + 0.22)	18 ab	43.87 ab	0.76 b
Sulfometuron + imazapyr (0.04 + 0.112)	18 ab	42.95 abc	0.76 b
Sulfometuron + hexazinone (0.08 + 0.45)	22 ab	44.07 ab	0.81 ab
Sulfometuron + imazapyr (0.08 + 0.056)	15 ab	36.80 bc	0.84 ab
Sulfometuron + imazapyr (0.08 + 0.112)	18 ab	38.58 bc	0.74 b
Sulf + imaz + hex (0.04 + 0.056 + 0.22)	26 b	37.19 bc	0.66 bc
Imazapyr (0.168)	15 ab	37.57 bc	0.69 b
Mean	18.9	40.16	0.76
Control	30 b	38.66 bc	0.48 c

See table 1 for conversion of kilograms ai per hectare to pounds per acre. Means in a column sharing the same letter do not differ significantly (Tukey's studentized range test, " = 0.05).

*Index check treatments. Total vegetation control was maintained in these plots with subsequent directed applications of a 3 % glyphosate in water solution at 60 and 120 days after treatment.

†Single over-the-top application of herbicide.

ception of imazapyr (0.279), did not stunt seedling growth nor did they increase seedling mortality (table 3). In the operational treatments, where vegetation was allowed to reinvade plots, mortality was comparable and growth equaled or exceeded that observed for the controls. Only the three-way mix of sulfometuron + imazapyr + hexazinone appeared to have any negative impact on seedling development.

On the other hand, relative to the seedlings in the controls, operational treatments did not produce the amount of positive response in height and diameter growth expected based on loblolly response to herbicide release reported by other authors (Creighton et al. 1987, Haywood and Tiarks 1981, Holt et al. 1973, Knowe et al. 1985, Nelson et al. 1981, Yeiser and Boyd 1989, Zutter et al. 1986). This suggests that factors other than competition may have inhibited the early response of newly planted seedlings. Soil moisture should not have been a limiting factor, although precipitation for the summer months (June-September) of 1990 was nearly 13 cm below normal, because controlling vegetation improves soil moisture availability to pine seedlings (Mitchell et al. 1991). Soil fertility may have been a factor, although fertility at this site is typical of most sites in northern Arkansas. Soils at the site were, however, highly compacted from previous agricultural practices and this compaction was probably the primary factor limiting seedling growth response to herbicide release. Managers should weigh the advantages of mechanical soil treatment, such as ripping, for reducing compaction in addition to vegetation management when planting pine on old field sites.

It was also apparent that height was less responsive to control of herbaceous weeds than ground line diameter (table 3). Seedlings in 4 of 7 operational treatments and 1 index treatment exhibited lower mean height than the controls (table 3). Based on the average of the index and operational treatments, heights of seedlings in treated plots exceeded the controls by about 5% (table 3). Diameter growth was greater for all treated plots versus the untreated check and exceeded the untreated check by nearly 70% (table 3). Zutter et al. (1986) observed similar trends in a study of height and diameter growth in relation to herbaceous competition on an Upper Coastal Plain site in Alabama.

Pine biomass. As was the case with growth analyses, a lack of precision in this experiment resulted in an apparent lack of statistical significance for biomass data. In spite of the lack of statistical evidence, we believe that differences in biomass production in treated versus untreated seedlings are biologically significant.

Root development was greater for all index treatments and operational treatments versus the untreated controls, although only sulfometuron (0.08) statistically increased root development (table 4). Sulfometuron is a mitotic inhibitor, and Barnes et al. (1989) found that it stunted root growth potential in loblolly pine seedlings. Yeiser and Barnett (1991) suspected that roots of shortleaf pine *(Pinus echinata .)* grown on a ripped site and treated with sulfometuron may have initially been stunted, but demonstrated that benefits from herbaceous weed control outweighed any initial stunting. In this abandoned field, we found no significant differences in root development among the index plots (table 4). For operational herbicide treatments, root systems for seedlings treated with sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22)showed the smallest average root biomass (table 4).

Pine seedling needle biomass was influenced by herbicide treatment and interfering vegetation (table 4). Six treatments (3 index treatments and 3 operational treatments) yielded seedlings with significantly greater needle biomass than those grown under herbaceous competition (table 4). Needle biomass was at least 3 times greater for all treatments except sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22), which still produced more than 2 times greater needle biomass than the untreated check (table 4).

First-year branch development was minimal for all treatments, as branches were the smallest component of total seedling biomass (about 7%) (table 4). Controlling herbaceous weeds around the pine seedlings did not influence first-year branch development.

Herbaceous competitors and herbicide treatment influenced stem biomass (table 4). All index and operational treatments produced mean stem biomass greater than the control treatment did and, in all but one case, stem biomass was at least 2 times more than that observed for the controls (table 4). Three index treatments and 4 operational treatments yielded seedlings with statistically greater stem biomass than controls (table 4). The addition of imazapyr to a sulfometuron + hexazinone (0.04 + 0.22) tank mix significantly reduced stem biomass yields. Including imazapyr in a sulfometuron + hexazinone tank mix could hypothetically increase the control spectrum for perennial weeds. However, the visible pine damage, inhibited height growth, and significantly lower stem biomass yields indicated that over-the-top application of this tank mix harmed the pine seedlings.

Reducing herbaceous competition with herbicides generally increased total pine seedling biomass (table 4). All index and operational treatments produced substantially more seedling biomass than untreated check seedlings (table 4). Although all operational treatments produced statistically similar biomass, the sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22) treatment produced

Table 4-*Mean weights for components of seedling biomass one growing season after treatment for perennial herbaceous weeds near Batesville, Arkansas*

	Weight (g)				
Herbicide treatment (kg ai/ha)	Root	Needle	Branch	Stem	Total
Index*					
Sulfometuron (0.08)	13.61 a	14.46 a	2.55 a	8.51 a	39.12 a
Hexazinone (0.67)	8.22 ab	10.77 ab	2.27 a	5.67 abc	27.22 ab
Imazapyr (0.168)	8.51 ab	10.49 ab	1.98 a	5.39 abc	26.37 ab
Imazapyr (0.279)	6.24 ab	7.37 abc	1.98 a	4.25 bcd	19.85 abc
Operational†					
Sulfometuron + hexazinone (0.08 + 0.45)	7.65 ab	10.21 ab	2.55 a	5.10 abc	25.52 ab
Sulfometuron + imazapyr (0.04 + 0.112)	6.80 ab	8.79 ab	1.70 a	5.39 abc	22.68 abc
Sulfometuron + hexazinone (0.04 + 0.22)	6.52 ab	6.52 abc	1.13 a	6.52 ab	20.70 abc
Sulfometuron + imazapyr (0.08 + 0.056)	6.24 ab	8.22 ab	1.42 a	5.39 abc	21.26 abc
Imazapyr (0.168)	5.10 ab	7.37 abc	1.13 a	4.54 abcd	18.41 abc
Sulfometuron + imazapyr (0.08 + 0.112)	6.24 ab	7.37 abc	1.13 a	3.97 bcd	18.71 abc
Sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22)	4.25 b	4.82 bc	1.13 a	2.84 cd	13.04 bc
Control	2.27 b	2.27 c	0.85 a	1.98 d	7.37 c

See table 1 for conversion of kilograms ai per hectare to pounds per acre. Means in a column sharing the same letter do not differ significantly (Tukey's studentized range test, " = 0.05).

*Index treatments. Total vegetation control was maintained in these plots with subsequent directed applications of a 3 % glyphosate in water solution at 60 and 120 days after treatment.

†Single over-the-top application of herbicide.

substantially less biomass than the other operational treatments (table 4). The sulfometuron + hexazinone (0.08 + 0.45) treatment was the only operational application that yielded statistically more total seedling biomass than did the control treatment (table 4). Three of the four index treatments yielded significantly greater biomass than controls, the exception being imazapyr (0.279) (table 4). Sulfometuron (0.08) produced the greatest biomass of the index treatments, with total biomass exceeding the imazapyr (0.279) index treatment by nearly 20 g/ha and exceeding control values by nearly 33 g/ha (table 4).

Biomass/cost ratio. Since many of the operational treatments provided similar herbaceous weed control and pine growth, a ratio of first-year stem biomass produced versus the cost for each treatment would be beneficial to the manager selecting an herbicide treatment. The approximate costs per hectare for herbicide ranged from $5.70 to $11.40 (table 5). Sulfometuron + hexazinone (0.08 + 0.45) produced the greatest biomass per dollar spent, although several other operational treatments produced statistically similar ratios (table 5). This ratio is not to be confused with cost effectiveness, which is determined at the end of the rotation and influenced by timely intermediate treatments such as thinning.

Table 5—*Relative first-year stem biomass per hectare, approximate herbicide cost per hectare and biomass/cost ratio of one-time operational herbicide applications for perennial weed control near Batesville, Arkansas*

Herbicide treatment (kg ai/ha)	Stem biomass (kg/ha)	Cost ($/ha)*	Biomass: cost ratio†
Sulfometuron + hexazinone (0.04 + 0.22)	7.53	5.70	1.32 a
Sulfometuron + imazapyr (0.04 + 0.112)	5.70	7.13	0.80 ab
Sulfometuron + imazapyr (0.08 + 0.056)	4.07	8.42	0.48 ab
Imazapyr (0.168)	4.02	5.83	0.69 ab
Sulfometuron + hexazinone (0.08 + 0.45)	5.15	11.40	0.45 ab
Sulfometuron + imazapyr (0.08 + 0.112)	3.28	10.36	0.32 ab
Sulfometuron + imazapyr + hexazinone (0.04 + 0.056 + 0.22)	1.46	7.64	0.19 b

See table 1 for conversion of kilograms ai per hectare to pounds per acre. Means in a column sharing the same letter do not differ significantly (Tukey's studentized range test, $\alpha = 0.05$).

*Cost of herbicide treatment per hectare (cost per acre = cost per hectare times 2.47); 1990 herbicide prices were used for relative comparison.

†Biomass/cost ratio is stem biomass per hectare/herbicide cost per hectare.

Conclusions

Seedling injury and mortality were less and height and diameter growth greater for most index treatments versus the controls. These results indicate that application of the individual herbicides studied did not stunt growth or otherwise interfere with loblolly seedling development independent of effects associated with herbaceous competition. It is apparent, however, that over-the-top application of the mixture that combined sulfometuron, imazapyr, and hexazinone harmed newly planted pine much more than other operational treatments.

Because most operational treatments provided similar growth and biomass yields with similar weed control and minimal visible seedling damage, economic considerations could be a major factor when selecting an herbicide for seedling release. For establishing loblolly pine on this old-field site, sulfometuron + hexazinone (0.04 + 0.22) yielded greatest first-year stem biomass per unit cost of herbicide.

Managers should carefully assess sites for herbaceous competition, soil compaction, and other conditions that may restrict growth and impose the combination of treatments, chemical and mechanical, that will insure a positive growth response for establishment of loblolly pine in old fields.

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Vesicular-Arbuscular Mycorrhizae of Western Redcedar in Container Nurseries and on Field Sites After Slash Burning

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Container-grown western redcedar (Thuja plicata *Donn ex D. Don) was virtually nonmycorrhizal when lifted from both Koksilah and MacBean Nurseries on Vancouver Island, British Columbia. After one growing season in the field on a variety of sites, most plants were colonized by fine and/or coarse vesicular-arbuscular mycorrhizal (VAM) fungi. Increased intensity of slash-burn produced a trend toward increased colonization by fine VAM and decreased colonization by coarse VAM fungi.* Tree Planters' Notes 44(1):33-37; 1993.

Western redcedar *(Thuja plicata* Donn ex D. Don) forms mutually beneficial root associations with fungi known as vesicular-arbuscular mycorrhizae (VAM) in bareroot nurseries (Berch et al. 1992), in pots inoculated with forest soils or VAM fungi (Kough et al. 1985, Parke et al. 1983 a&b), and in nature (Carpenter and Trappe 1970). There is no published information on the mycorrhizal status of western redcedar in containerized nurseries of British Columbia, although Castellano and Molina (1989) predict that susceptible conifer hosts, including western redcedar, will not form mycorrhizae when grown in completely artificial media like peat-vermiculite.

Although western redcedar may not need its mycorrhizal fungi in nurseries where ample water and nutrients are supplied, the time immediately after outplanting is critical to the survival and vigor of seedlings. Thus, it is important that they form mycorrhizae quickly on sites where nutrients or water limit growth. Nothing has been published on the early mycorrhizal colonization of western redcedar on clearcuts, so it is possible that nonmycorrhizal container-grown seedlings planted into clearcuts may suffer from a lack of VAM inoculum, particularly if the soil has been disrupted by site preparation techniques such as slash burning.

Two studies are described here. The objectives of both were to determine the VAM status of western redcedar produced by container nurseries in south coastal British Columbia and the changes in VAM status occurring in these seedlings after outplanting.

Materials and Methods

Study sites and sampling. Study A was carried out in 1987-1988 using seedlot Cw4511 produced in the MacBean Nursery of MacMillan Bloedel Ltd., Nanaimo, British Columbia. Seeds had been planted in February to March 1987 in peat-vermiculite in containers, and seedlings were lifted February 1988 and cold-stored for 1 to 2 months. They were then outplanted onto a flat site east of Duncan, BC, in the coastal western hemlock biogeoclimatic zone, moist maritime subzone (CWHmm, Nuszdorfer et al. 1985) at 670 m elevation. The site had received a low-impact prescribed burn in the spring before planting. The soil was a well-drained to rapidly drained Humo-Ferric podzol with upper mineral soil at pH 4.6 (H_2O extractant). Dominant vegetation before burning consisted of salal *(Gaultheria shallon* Pursh), Oregon-grape *(Berberis nervosa* Pursh), blueberry species *(Vaccinium alaskaense* Howell and *V. parvifolium* Smith) and fireweed *(Epilobium angustifolium* L.). Spotted cats-ear (Hypo*chaeris radicata* L.), woodland groundsel *(Senecio sylvaticus* L.), and western hemlock *(Tsuga heterophylla* (Raf.) Sarg.) were also common. Twenty-five young cedars were randomly sampled from Styroblocks before outplanting in March (when the seedlings were 12 to 13 months old) for assessment of VA mycorrhiza development and size in the container nursery. Twenty-five other seedlings were randomly sampled after one growing season in September by excavating entire root systems for assessment of VA mycorrhizal colonization and growth.

Study B was carried out on sites burned in 1985 as part of a cooperative MacMillan Bloedel/ Forestry Canada study on the effects of prescribed fire on forest nutrition and productivity. The four sites were located in Sproat Lake Woodlands Division of MacMillan Bloedel Ltd., west of Port Alberni, BC, in the CWHmm biogeoclimatic subzone. All sites are south aspects between 450 and 600 m in elevation. Vegetation prior to planting was similar to that listed for study A, except that spotted cats-ear, woodland groundsel, and western hemlock were not common. The soils were Orthic HumoFerric podzols with upper mineral soil at pH 4.5 to 5.1.

The four sites had received different site preparation before planting:

1. Unburned control
2. Low impact burn in spring 1985
3. Moderate impact burn in fall 1985
4. Severe impact burn in fall 1985

Sites 1 and 2 were adjacent; site 3 and 4 were at separate locations. The light bum consumed 25% of the forest floor by weight and exposed 4% of the mineral soil. The moderate burn consumed 47% of the forest floor by weight and exposed 29% of the mineral soil. The severe bum consumed 67% of the forest floor by weight and exposed 74% of the mineral soil. Further details of burn impacts are available (Beese 1992).

A total of 150 western redcedar seedlings (seedlot Cw7303, Koksilah Nursery, Duncan, British Columbia) were examined: 25 before cold storage (at the end of January 1986, 11 to 12 months after seeding); 25 after storage (mid-March 1986); and 100 at the end of the first growing season (November 1986, with 25 from each treatment: control, light impact, moderate impact, severe impact). Only 20 seedlings per treatment were examined for mycorrhizal colonization, as 5 seedlings per treatment were sacrificed for root weight measurements. All 25 seedlings from each treatment site were assessed for height and caliper and shoot dry weight.

Mycorrhizal colonization. For study A at all times, the entire root system was examined for mycorrhizal colonization, with the plug roots being assessed separately from the new roots. For study B at all times, the extent of VAM colonization was determined on approximately 2 g (wet weight) per seedling of cedar roots less than 1 mm diameter. For both studies, percentage root colonization was determined using the gridline intersect method (Giovannetti and Mosse 1980) after clearing in KOH and alkaline H_20_2 then staining in trypan blue (Kormanik and McGraw 1982). Based on presence or absence of VAM, the percentage of seedlings that were mycorrhizal was also determined.

Also for both studies, five to ten 1-cm-long colonized root segments per seedling were mounted on microscope slides and examined at 500 x to distinguish between coarse and fine VAM endophytes and other nonmycorrhizal root-inhabiting fungi. Coarse VAM endophytes have hyphae approximately 5 µm diameter, vesicles approximately 50 to 100 µm long, and spores generally 50 to 1000 µm long that form in the soil or in roots. This contrasts with fine VAM endophytes, which have hyphae that are 2 to 3 µm diameter, vesicles 5 to 10 µm long, and relatively small spores (10 to 15 µm long). Presence or absence of fine and coarse endophytes was recorded but the endophytes were not evaluated separately for extent of roots colonized.

Only in study B were some of the data analyzed statistically. Because data were not normally distributed for the adjacent unburned and low-impact burn sites, the difference in percentage colonization was analyzed using the Mann-Whitney U test (Siegel 1956). Data from the moderate-impact and high-impact burned sites were not included in the analysis because appropriate on-site controls had not been included in the experimental design.

Plant growth. Plant growth was assessed to ensure that plants were growing reasonably well. When outplanted seedlings were harvested, shoot height, caliper, and dry weight were measured. Root dry weight was determined by converting from fresh weight. For 5 seedlings per plot per treatment site, roots were weighed fresh, dried at 100 /C for 24 h, and then reweighed dry. From these data, a conversion factor was determined so that root fresh weight of the other seedlings could be converted to dry weight. Data from the control and low-impact burn sites were compared using the student t test (Snedecor and Cochran 1967).

Results and Discussion

In study A, post-storage redcedars were virtually nonmycorrhizal (table 1). In study B, only 10% of the pre-storage seedlings and 5% of the poststorage seedlings were mycorrhizal, and of these, the extent of mycorrhizal colonization in each seedling was low, with less than 1% of the roots colo-

Table 1 -*Summary of growth and mycorrhizal colonization for western redcedar before and after outplanting*

Treatment	Location*	Height (cm)	Caliper (mm)	Dry weight (g)		Shootroot ratio	% of seedlings with VAM	% of live roots with VAM
				Shoot	Root			
Study A								
Post-storage	-	27.8	2.6	1.3	0.6	2.2	0	0
Low-impact fire	7c	32.5	3.9	2.9	1.7	1.7	60	8 (plug) 15 (new)
Study B								
Pre-storage	-	-	-	-	0.5 (25) a	-	10	<1 a
Post-storage	-	-	-	-	0.4 (28) a	-	5	<1 a
Unburned	C	38.3 (±4.4) a	3.6(± 0.5) a	2.7(± 0.7) a	1.1(± 0.4) b	2.8(± 1.1) a	95	22.3(± 13.4) b
Low-impact fire	C	40.5(± 4.9) a	4.2(± 0.5) b	4.1(± 1.5) b	1.2(± 0.4) b	3.7(± 0.8) b	95	31.5(± 18.4) b
Medium-impact fire	K	35.5	4.1	3.4	1.2	3.1	90	28.1
High-impact fire	M	35.3	4.4	4.0	1.5	2.9	85	17.4

Values are mean and (standard deviation). Means within columns not followed by a common letter differ at $P< 0.05$ using Bonferroni significance levels.
\- = data not available.
*Location: 7c =Duncan, C = Cous, K = Kanyon, M = Mactush.

nized. These findings are in agreement with what Castellano and Molina (1988) had predicted of VAM-forming conifer seedlings grown in peatvermiculite potting mix in container nurseries. In contrast, in a bareroot nursery bed in southwestern British Columbia, western redcedar fine roots can be over 50% VA mycorrhizal (Berch et al. 1992). Most VAM fungi, notably those known as coarse endophytes, are not readily disseminated in air or water because their propagules consist of large spores formed in the soil or in roots, colonized root fragments, or hyphae attached to colonized roots. This contrasts with the situation for fine VAM endophytes, which have relatively small spores that may be capable of easier dispersal through air and water. Similarly, pines, firs, spruce, and most other North American conifers of commercial importance associate with ectomycorrhizal fungi, many of which are wind or water disseminated.

For study A, 60% of seedlings and for study B, 85% or more of seedlings were colonized after one growing season in the field (table 1). In study A, virtually all nonmycorrhizal seedlings from the MacBean Nursery had been colonized 6 months after outplanting and the mean percentage colonization was about 8% for roots in the original plug and 15% for roots that had grown out of the plug. These levels were slightly lower than those found in study B, which averaged from about 17 to 32%. In study A, plants were harvested 6 months after outplanting, while in study B, plants were harvested after 8 months. During the fall, root growth may slow, permitting the mycorrhizal fungi to colonize a greater proportion of the fine roots. The vegetation on site for both studies before burning included Oregon-grape, which is commonly VA mycorrhizal and the roots of which could serve as a source of inoculum for cedars planted after a relatively low-impact slash burn.

Since the unburned site was not adjacent to the moderate and severely burned sites, it cannot serve as a control for these two treatments and we cannot compare the sites directly. However, on the adjacent low-impact burn and unburned sites, 95% of the seedlings on both sites had formed VAM (table 1). Percentage colonization of roots was not significantly greater after the low-impact burn (32%) than on the adjacent unburned control area (22%) even though shoot caliper, shoot dry weight, and shoot-root ratios were significantly higher than those of the control. This suggests that the light burn had little or no effect upon VAM colonization but promoted plant growth (except root weight), perhaps through weed suppression or release of available nutrients. In study A, the cedars were planted on another site pretreated with a lowimpact burn. Although the extent of colonization was lower on this site (15% for roots outside of plugs) than the low-impact burn site in study B, this may have been due to the shorter time in the field.

Despite the lack of statistical analysis for the comparison of unburned and low-impact slashburned sites with the moderate-impact and highimpact slash-burned sites, some general trends were evident. Percentage of seedlings mycorrhizal showed a decreasing trend with increasing intensity of burn (table 1) in study B, assuming equal preburn levels of inoculum among sites. We also observed a trend toward a greater proportion of the mycorrhizal seedlings on the unburned site having only coarse endophyte VAM than on any of the burned sites (figure 1). The number of seedlings with only coarse endophyte VAM seemed to decrease as burn intensity increased. The high-impact burn had a greater proportion of seedlings with only fine endophyte VAM than any of the other sites, with a decreasing trend as burn intensity decreased. This suggests that burning may have an adverse impact on coarse endophyte VAM and a favourable impact on fine endophyte VAM, but this hypothesis would have to be tested.

The fine endophyte type is known to be most common on harsh sites, such as low-pH soils (Wang et al. 1985), high elevations (Crush 1973), and coal spoils (Daft et al. 1972). In a prefumigated nursery bed in southwestern British Columbia, bareroot western redcedar was colonized only by fine endophyte, whereas plants in the nonfumigated bed were colonized by fine and coarse VAM endophytes (Berch et al. 1992).

Recommendations

The lack of mycorrhizal colonization of western redcedar in peat-vermiculite mixes of containerized nurseries is of particular interest because it provides nonmycorrhizal controls that could easily be compared with seedlings inoculated with VAM fungi obtained from commercial sources or raised on host plants in pot culture. In contrast, ectomycorrhizal fungi spread easily in nurseries, and noninoculated plants often become mycorrhizal before the experiment is concluded, which confounds the interpretation of nursery-based experiments with ectomycorrhizal fungi. Thus, for studies of mycorrhizal fungi as agents of biocontrol of root diseases or as means of improving fertilizer efficiency under operational conditions, VA mycorrhizae would be a superior test system.

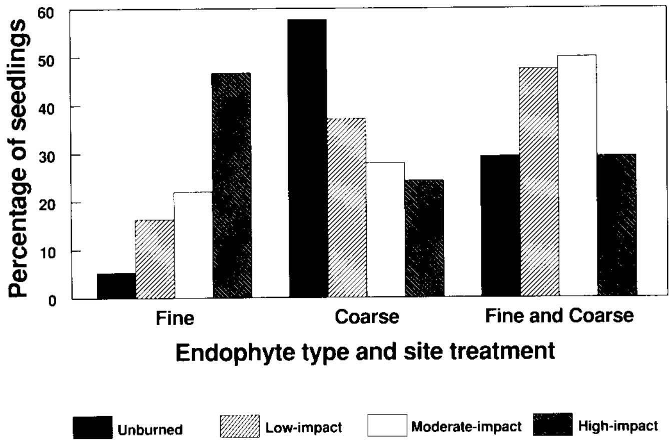

Figure 1—*Relative proportions of mycorrhizal western redcedar seedlings colonized by only fine, only coarse, or fine and coarse vesicular-arbuscular endophytes one season after outplanting on clearcuts having received different intensity slash burns.*

Observations from this work and the literature indicating that fine endophyte VAM may be more resistant to stresses, including severe burn, suggest some questions worthy of future study. Are propagules of the coarse endophytes more susceptible to burning, fumigation, and other stresses than those of fine endophytes? Are fine endophytes stimulated to sporulate by burning or other stresses? Are fine endophytes more rapidly dispersed to disturbed sites than coarse endophytes? Are fine and coarse VAM fungi equally capable of contributing to the growth of western redcedar?

The main conclusions of this study are that western redcedar remains virtually nonmycorrhizal in container nurseries in British Columbia but develops VAM on a variety of clearcut sites within one growing season of outplanting. The suggestion that fine VAM fungi may be found more commonly than coarse VAM fungi after high-impact slash burn would have to be examined more extensively. The fact that western redcedar seedlings produced in containerized nurseries are nonmycorrhizal when lifted would present a situation where inoculation with selected VAM fungi, whether fine or coarse, could be easily carried out with minimal risk of cross-contamination.

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Hardwood Species Trials in Oregon

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Survival and growth of a wide variety of native Pacific Northwest and non-native hardwood tree species were evaluated at six sites in Oregon with different climatic and soil conditions. Hybrid cottonwood performed particularly well---it had a mean survival rate of 90% and a mean height of 634 cm after 5 years. Several other species also performed well, including black cottonwood (Populus trichocarpa *Torr. & Gray), cherrybark oak* (Quercus falcata *var.* pagodifolia *Ell.), Nuttal oak* (Q. nuttallii *Palmer), water oak* (Q. nigra *L.), black cherry* (Prunus serotina *Ehrh.), black walnut* (Juglans nigra *L.), green ash* (Fraxinus pennsylvanica *Marsh.), Oregon ash* (F. latifolia *Benth.), and white ash* (F. americana *L.). Suggestions for selecting appropriate species for particular sites and for their management are included.* Tree Planters' Notes 44(1):3842; 1993.

Many Oregon landowners have land that is underutilized for timber or agricultural production and could support hardwood species as a crop. In addition, there is a growing interest in tree species that can be used in agroforestry systems. Unfortunately, little information on species' site requirements and production rates is available to help these landowners select appropriate species. In an attempt to fill this information gap, a wide variety of hardwood species was planted at six locations across eastern and western Oregon in order to assess the potential for establishing these species over a range of site conditions as well as to identify the conditions in which the species grow best.

Methods

The six sites used for the species trials (table 1) were selected to represent a variety of climate and soil combinations; characteristics ranged from low precipitation (in eastern Oregon) to high precipitation (in the Coast Range) and from heavy clays to sandy loams.

Each site consisted of 3 replicate blocks of 12.2 m (40 feet) X 12.1 m plots; each square plot contained 25 trees of one of the test species, planted at 2.4-m (8-foot) spacing. The inner 9 trees of each plot were measured yearly, over a 5-year period, for basal diameter, diameter at breast height, and height. Qualitative descriptions of seedling condition were also recorded annually. Before planting the hardwoods, all vegetation was removed from the sites and the sites were treated with chemical herbicides. Subsequent site maintenance consisted of partial mechanical and chemical weed control as needed.

The hardwood species planted at each site included both natives and exotics, and they were selected on the basis of potential value at maturity, growth rate, and site suitability (table 2). All stock consisted of bareroot 1-year-old seedlings except for cottonwood and willow species. These were planted as 30.5-cm (12-inch) to 38.1-cm (15-inch) cuttings of 1year-old shoots. Seedlings were either purchased from commercial nurseries or grown from seed in the College of Forestry nursery; no effort was made to control or account for the seed-source location within a species range. Cottonwood hybrid #11 came from the joint University of Washington/ Washington State University breeding program and is a cross between *Populus trichocarpa* and *P. deltoides.* The black cottonwood cuttings planted at the Warren and Westport sites were collected along the Nisqually River in southern Washington and the Santiam River in western Oregon. The black cottonwood cuttings planted at the Corvallis and Lebanon sites were collected along the Santiam River. Black cottonwood planted at the Union site came from local cuttings.

Results and Discussion

The rate and success of seedling establishment over a 5-year period varied widely among species and sites. Several species died soon after planting and had to be replanted or replaced with other species. Others grew poorly or died within the 5-year period due to drought. Browsing by deer, rabbits, and gophers also contributed to poor growth rates, as did competing weeds. Frost damage was particularly prevalent among *Eucalyptus* species, but resprouting generally occurred during the next growing season; only red alder at the Corvallis site died from frost damage.

Table 1 -*Site characteristics for the six test sites in Oregon*

Site	Year established	Soil type	Mean monthly precipitation (cm)		Mean monthly temperature (/C)		Level of weed control
			Winter	Summer	Winter	Summer	
Warren	1984	Clay loam	11.7	4.3	6.7	16.1	Good
Westport	1984	Silt loam	17.5	4.1	6.7	15.6	Excellent
Siletz	1985	Sandy loam---alluvial	29.2	6.9	11.7	15.3	Poor
Union	1985	Clay loam---high organics, seasonally flooded	3.0	3.0	3.9	15.6	Poor
Corvallis	1987	Sandy loam---river floodplain, well drained	13.5	2.8	11.1	16.7	Fair
Lebanon	1987	Clay---shallow depression, seasonally flooded	15.7	4.8	7.8	16.7	Fair

Table 2- *Hardwood species tested and planting sites in Oregon*

Common name	Scientific name	Site
bigleaf maple*	*Acer macrophyllum* Pursh	War, Wes, Cor, Leb
black cherry	*Prunus serotina* Ehrh.	War, Cor
black cottonwood*	*Populus trichocarpa* Torr. & Gray	War, Uni, Wes, Cor, Leb
black locust	*Robinia pseudoacacia* L.	Uni, Leb
black walnut	*Juglans nigra* L.	War, Wes, Cor
Brazilian willow	*Salix* spp.	Leb
cherrybark oak	*Quercus falcata* var. *pagodifolia* Ell.	War, Wes, Cor, Leb
cottonwood hybrid #11	*Populus trichocarpa* X *deltoides*	War, Wes, Cor, Leb
	Eucalyptus glaucescens	War, Sil, Cor
	E. *gunnii*	War, Cor
	E. *nitens*	Sil
	E. *urnigera*	War, Sil
green ash	*Fraxinus pennsylvanica* Marsh.	War, Uni, Wes, Cor, Leb
imperial poplar	*Populus* spp.	Uni
northern red oak	*Quercus rubra* L.	War, Cor, Leb
Norway maple	*Acer plantinoides* L.	Uni, Leb
Nuttal oak	*Quercus nuttallii* Palmer	War, Wes, Cor, Leb
Oregon ash*	*Fraxinus latifolia* Benth.	War, Cor, Leb
Pauwlonia	*Pauwlonia tomentosa* (Thunb.) Sieb. & Zuch ex Steud.	War, Cor, Leb
pin oak	*Quercus palustris* Muenchh.	Uni, Cor, Leb
red alder*	*Alnus rubra* Bong.	War, Cor, Leb
red maple	*Acer rubrum* L.	Uni
silver maple	Acer *saccharinum* L.	Uni
sycamore A	*Platanus occidentalis* L.	War
sycamore B		War
sycamore C		War
yellow-poplar	*Liriodendron tulipifera* L.	Wes
water oak	*Quercus nigra* L.	War, Cor, Leb
white ash	*Fraxinus americana* L.	War, Wes, Cor
windbreak poplar	*Populus* supp.	Uni

Cor = Corvallis, Leb = Lebanon, Sil = Siletz, War = Warren, Wes = Westport, Uni = Union; see table 1 for characteristics.

*Native trees of the Pacific Northwest.

Species survival and height data (table 3) at the end of the 5-year establishment period provide a good indication of which species will grow successfully over the range of site conditions we tested. These data generally reflect the species' minimum level of performance; placing more emphasis on weed control and seed source would have improved performance in many cases. Our intent was simply to examine the interaction between species and sites to identify species that deserve further attention in specific environments. The following paragraphs summarize our findings.

Table 3 -*Hardwood mean survival and mean height (survival (%)/height(cm)) after 5 years at 6 Oregon sites*

Species	Warren	Union	Siletz	Westport	Corvallis	Lebanon	Species Average
Oak							
cherrybark	100/111	-	-	80/320	67/114	87/41	84/147
Nuttall	98/158	-	-	100/383	67/40	87/43	88/156
pin	-	4/19	-	-	55/25	84/31	48/25
northern red	92/157	-	-	-	48/36	48/25	63/73
water	93/115	-	-	-	83/92	91/44	89/117
Ash							
green	100/132	51/85	-	99/450	97/77	96/66	89/162
Oregon*	100/210	-	-	-	92/77	100/59	97/115
white	96/145	-	-	99/405	72/69	-	89/206
Maple							
bigleaf*	98/257	-	-	99/497	67/130	35/37	75/230
Norway	-	37/69	-	-	-	51/42	44/56
red	-	3/90	-	-	-	-	3/90
silver	-	13/39	-	-	-	-	13/39
Cottonwood							
cottonwood hybrid #11	100/808	-	-	91/996	76/635	91/95	90/634
black cottonwood*	95/738	0/-	-	100/982	41/255	-	59/494
imperial poplar	-	17/137	-	-	-	-	17/137
windbreak poplar	-	4/141	-	-	-	-	4/141
Other							
black walnut	97/89	-	-	77/346	73/90	-	82/175
black cherry	95/140	-	-	-	69/204	-	82/172
Brazilian willow	-	-	-	-	-	67/58	67/58
Eucalyptus umigera	12/-	-	65/194	-	-	-	39/97
Eucalyptus nitens	-	-	1 /27	-	-	-	1 /27
Eucalyptus glaucescens	11/-	-	63/154	-	80/575	-	51/243
Eucalyptus gunnii	39/265	-	-	-	80/418	-	60/342
Paulownia tomentosa	88/405	-	-	-	0/-	3/22	30/142
red alder*	100/598	-	-	-	0/-	20/74	40/224
sycamore A	96/207	-	-	97/209	-	-	97/208
sycamore B	92/173	-	-	-	-	-	92/173
sycamore C	96/104	-	-	-	-	-	96/104
yellow-poplar	-	-	-	60/474	-	-	60/474
Site average	85/241	16/73	43/125	90/506	63/167	66/49	

- =not present at site.
*Native trees of the Pacific Northwest.

Oak species. Across all sites and all oak species we tested, mean survival was 76% and mean height was 103 cm. Cherrybark, Nuttall, and water oak all had higher than average survival and growth rates at all sites on which they were established: Mean survival across all sites was 87%, and mean height was 133 cm. The lowest single-site mean survival rate for the three species (67%) occurred at the Corvallis site, possibly because of the site's sandy soil and relatively low precipitation compared to the other sites. Summer precipitation, in particular, was as much as 2.0 cm (0.8 inch) per month less at the Corvallis site than at the other western Oregon sites. Only cherrybark and water oak maintained their growth on this site.

The two remaining oak species we tested, red oak and pin oak, performed poorly at almost all sites. Even at sites where their survival was above average, their height was usually low. No oak species did well in the wet clay of the Lebanon site.

Ash species. With the exception of green ash at the Union site and white ash at the Corvallis site, survival of the three ash species we tested was among the highest in the species trials, typically well above 90%. For the three species combined, mean survival across sites was 91%.

All of the ash species had greater height growth on the Warren and Westport sites; height at other sites averaged approximately half that of these two sites after 5 years. Combine mean height for all ash species across all sites was 161 cm.

Maple species. Except on sites that were both moist and fertile, the four maple species we tested performed poorly. For example, mean survival was only 18% for the maple species planted at the dry Union site and only 43% for those planted at the wet, clay-soiled Lebanon site. Across all sites and maple species, mean survival was 50% and mean height was 145 cm. With a mean survival rate of 75% and mean height of 230 cm across all sites, bigleaf maple performed the best of the maple species and grew especially well at the Warren and Westport sites.

Cottonwood species. Of the cottonwood species we tested, hybrid #11 showed excellent survival and height growth. Hybrid #11 was perhaps the best-performing entry in the trials. Across the four sites at which it was planted, mean survival was 90% and mean height was 634 cm. In fact, even with a relatively low survival rate at the Corvallis site (76%) and a low height measurement at the Lebanon site (95 cm), hybrid #11 still outperformed all other species at these sites. Black cottonwood also clearly outperformed other species at the Warren and Westport sites. Survival was low at the Corvallis site although height growth was exceptional. The three cottonwood species planted at the Union site (black cottonwood, imperial poplar, and windbreak poplar) had poor survival rates and height growth.

Other species. Black cherry and black walnut were inconsistent in survival and height growth. Both species had an 82% mean survival rate across sites and had similar mean heights after 5 years (172 and 175 cm, respectively). On sites where both were planted, black cherry outgrew black walnut in height. Black cherry generally had a branchy form, whereas first-year dieback was common for black walnut.

Native versus exotic species. It is difficult to make any generalizations about the relative performance of native Pacific Northwest species versus non-native species. Some exotics, such as the southern oaks (cherrybark, Nuttall, and water oaks), performed quite well; the eucalyptus species, however, which froze to the ground and resprouted at least once, must be considered failures. Among the native Pacific Northwest species, establishment was best on sites with climate and soil conditions similar to those where the species are found naturally.

Conclusions

Success of species was considered a function of survival and growth. The minimum acceptable survival rate for successful species was 70%. A 5-year height greater than 75% of a species' average 5-year height in its native habitat was considered successful growth. In addition to these criteria, there are several others that could be used to characterize successful species. Site adaptability, stress tolerance, and sensitivity to competition are all characteristics that may be important to landowners. It would be difficult to assess success of individual species based on these characteristics, however, without knowing a landowner's values and needs. Nonetheless, the information presented in this paper should assist landowners in selecting potentially successful species given their situation.

Figure 1 shows the successful hardwood species (according to the success criteria cited in the preceding paragraph) at each experimental site. Only the five topperforming species for survival or growth category are listed for each site. In most cases, less than 5 species were successful in one or both categories. At Union and Siletz, no species were successful. In examining this table for potential crop species, the following points should be considered. First, the importance of a site's soil and climate characteristics in determining which hardwood species will grow successfully should not be underestimated. Although most of the species used in these trials were successful on sites with ample moisture and fertile soil, only cottonwoods were successful across the full range of sites, and only with good site preparation, weed control, and animal fencing. Second, performance of some species differed dramatically among sites. On sites where the environment approaches the edge of a species' natural tolerance, stress due to animal browsing and weed competition is magnified, and the importance of protecting against these factors increases. If a good site maintenance program is established from the beginning, many of the successful species (as identified in these trials) will be large enough in 3 to 4 years to withstand pressure from animals and other plants. Tilling between trees several times during the growing season is a successful and efficient method of weed control. Chemical herbicides are also effective for weed control, but only if directed toward a broad range of weed species. Because some hardwood species are very sensitive to chemical herbicides, care must be taken to apply the smallest possible amount of chemical that provides adequate weed control, and seedlings must be protected during herbicide application.

Third, many of the tested species had growth rates that were slow initially but that later improved. Thus, the 5-year height data reported in table 3 may not reflect a given species' full poten-

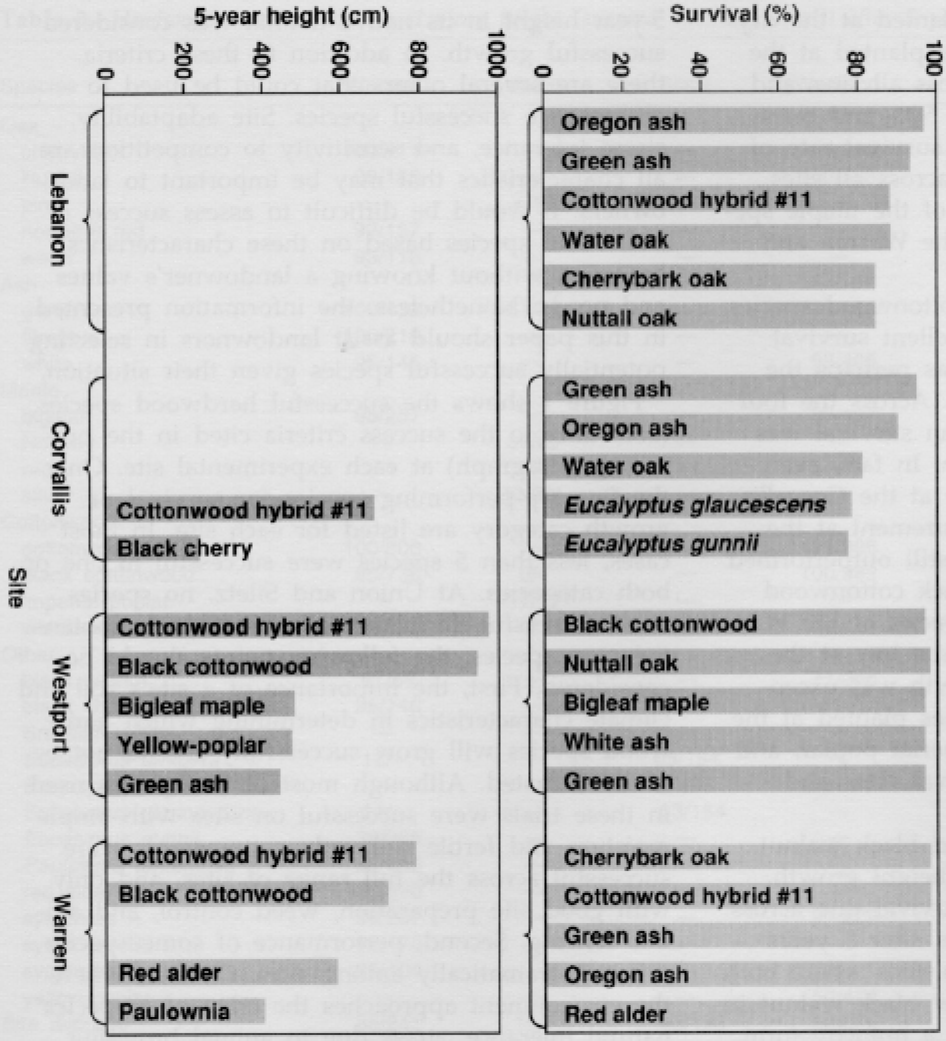

Figure 1—*Successful hardwood species by site. According to this study's success criteria for survival and growth (see text), no species were successful in either category at Union or Siletz.*

tial. The period of slow growth might be shortened by more complete elimination of competing vegetation. Proper seed-source selection could also improve performance of some of the species.

And finally, the trial results that appear in table 3 should be interpreted cautiously for species that performed poorly. Seedling establishment is closely related to the level of competing vegetation present on a site, so that a greater degree of weed control might have led to greater success in establishing some of the species that performed poorly in this study. In addition, the long-term growth potential of any of the tested species has yet to be determined; long-term survival does not necessarily follow from successful initial establishment.

Nevertheless, these species trials have provided some basic information for use in identifying hard wood species with high management potential in Oregon. The trials have also demonstrated that hardwood establishment is often difficult and re quires a well-planned maintenance program. The high growth rates and value of hardwood species may compensate for the effort required to establish these trees.

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