Seedling Counter Field Tests

Dave Gasvoda and Diane Herzberg

Electronic engineer and mechanical engineer
Missoula Technology and Development Center, Missoula, Montana

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.

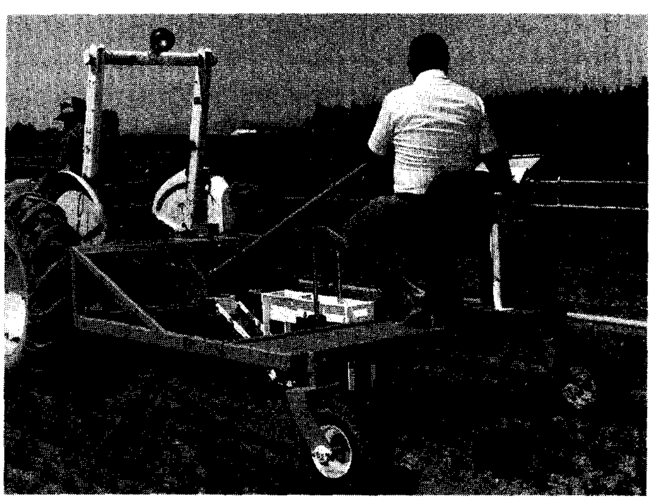

Figure 1—*The Missoula Technology Development Center's seedling counter.*

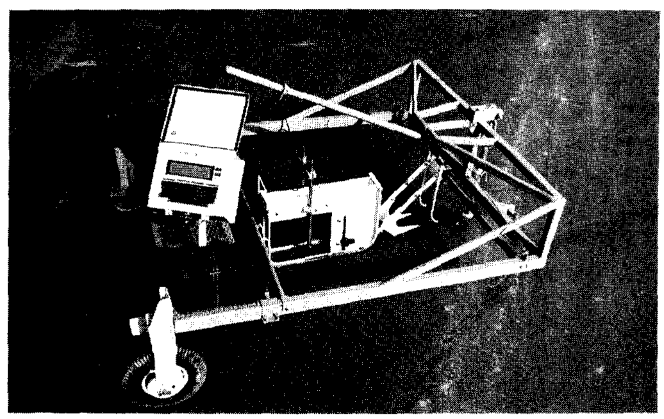

Figure 2—*A portable computer and opto-electronics combine to count seedlings.*

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).

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.

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

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