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Tree Seed Handling and Management--Part I

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Participants in recent nurseryman's conferences around the country have asked for a reference series to help them with their seed handling. The 48 topics they proposed will be covered in a series of articles here in Tree Planters' Notes. Tree Planters' Notes 37:3-7; 1986.

1. Seed moisture--How dry is too dry?

Under most conditions of seed extraction in the South, the moisture of the seed upon arrival at the container is between 9 and 12 percent. However, during humid weather, such as a week of rain, the seed may have a moisture content between 12 and 16 percent when removed from the kiln.

Research has shown that the moisture threshold for the seed of most tree species is around 10 to 12 percent, except for the recalcitrant seed, such as acorns. Seed of the family Fagaceae require moisture contents above 20 percent to maintain viability. These species are considered short lived and usually are stored for no more than one season.

Conifer seed, on the other hand, may be stored for long periods of time, with few exceptions, if the moisture content is below the threshold value of 10 to 12 percent. Seed of most conifers can be stored satisfactorily at 34 °F with an 8 to 10 percent moisture content when the seeds are sealed in moisture-proof containers. This may present a problem, because there is no margin of safety, and seed temperatures could increase rapidly if compressors stop working in the middle of the summer.

Chemical changes that begin at temperatures above 40 °F usually lead to germination or deterioration. Therefore, most nursery managers store their seed at 20 to 25 °F. This range provides a margin of safety for the seed. The typical insulated storage unit will hold seed temperatures below 40 °F for 48 to 72 hours during a power loss. This period is sufficient for emergency repairs. At this temperature range, the moisture content should be held between 6 and 8 percent. Moisture contents close to 10 percent will tend to increase above a safe level because condensation will form on the seed when the lid is removed for repeated sampling. Higher moisture contents also permit chemical changes to progress, even though slowly, at freezing temperatures, resulting in green embryos within the seed.

Some nursery managers store seed in a commercial freezer. These freezers, designed for preservation of food, maintain a temperature of 0 °F. Under these conditions the moisture content of the seed should be reduced to 4 to 6 percent because moisture may crystallize within the cell at or below this temperature. If there is too much moisture, the cell walls will be damaged, thus leading to deterioration.

The drier the conifer seed, the longer it will store. Samples of red pine (*Pinus resinosa* Ait.) and loblolly pine (*P. taeda* L.) were stored at a moisture content of 1 to 2 percent for 5 years, with annual testing. Viability was consistently above 95 percent. Low moisture levels may be detrimental at high temperatures because the cells are unable to repair damage without sufficient moisture for the necessary chemical reactions. However, seeds held at the same low moisture appear to be superior to seeds held at a higher moisture content for long-term storage. How low the moisture is not as important as how the low moisture content was reached. Super-low moisture contents (below 5 percent) must be reached slowly with dry air but without excessive heat. High heat may denature enzymes and kill cells. Relative humidities of 20 to 35 percent will produce very low moisture contents in about 10 days under natural conditions (without artificial heat).

If the seed are dried too fast, the moisture is removed from the seed surface faster than it can be moved to the surface from internal cells. This problem creates a differential pressure between cell layers, which I call a "vapor lock." This vapor lock prevents the seed from germinating until the cell pressure is equalized. This phenomenon can be seen by using microwave

drying in a pressure chamber. Seed dried this fast appear to be extremely dormant. They appear to store well but must be hydrated before being stratified. This step is accomplished by placing the seed on a moist surface or in a high-humidity atmosphere for 24 hours.

In summary, the nearer the moisture content of most conifers is to 4 percent, the better for extended storage. Seed stored for 5 years or less may not benefit from the added cost of superdrying the seed. A moisture content of about 9 percent is satisfactory if the seed are frozen. Storage for 1 year or less is possible at a 10-percent moisture content, providing the temperature remains below 40 °F and the moisture content does not increase further.

2. Seed sizing-How much is too much?

The objective of seed sizing is to obtain more uniform sowing and thereby achieve more uniform seedbed densities. Except for Douglas-fir (*Pseudotsuga menziesii*), seed sizing effects have not been found to carry beyond the nursery. Also, in contrast to many articles written on the possible elimination of clones by sizing, there is no possible way to eliminate clones without throwing some of the seed away. At the present value of seed, no one would want to throw away seed, no matter how small or large. However, two problems have led some seed managers to discard seed: the seed were too small to handle or the lot contained too much trash.

Before sizing seed, remove all trash and, if gravity separation is to be used, employ screen sizing first. Gravity can only separate one characteristic at a time. Seed cannot be separated for physical size and density at the same time. Recent studies have shown that physical, sizing (screens) account for 90 percent of the benefit in uniform densities. Therefore, serious evaluations should be made before gravity sizing is considered.

The more sizes obtained, the greater the record-keeping and handling. Increasing the number of the sublots also increases other problems of management. As an example, an 800-pound seedlot of pine seed may be sized into three sizes or into five sizes as indicated below.

Seed sizes (screen holes)	Sublot size (lb)	
	Trial A	Trial B
14		42
16	173	131
18	463	463
22	164	158
24		6

Observe that in separating into five sizes, two sublots were obtained with less than 50 pounds each. The minimum lot size should be that required to fill the planter being used. If the planter required 30 pounds, the 6-pound sublot would be mixed with the next size. We must remember that we are striving for more uniform density, not increased record keeping.

Secondly, the question is raised, "How different are these sizes?" The answer is found by computing the number of seed per pound. An example of the seed per pound on the lots sized above is given in the following table:

	Trial A		Trial B	
Seed sizes	Seed/lb	diff.	Seed/lb	diff.
14			19300	
		—		400
16	19000		18900	
		400		300
18	18600		18600	
		2400		2300
22	16200		16300	
				1800
24			14500	

The question arises, "How much difference is required before the planter makes a difference in seed per foot being planted?" Obviously, the more precise the planter, the smaller the difference that will result in a change in density per square foot of bed. Also, the smaller the seed the greater the difference required between sizes to create a difference on the seedbed.

Data from two planting machines showed that less precise machines like the Oliver planter required differences in seed size of more than 2,500 seed per pound before seedlings per square foot changed. The more precise Love planter provided differences in density with differences in seeds per pound of 1,000 seed.

In the examples above, the three sizes will provide only two different densities when sown because none of the planters used would discern differences in size of 400 seed per pound. Therefore, lot A (for practical reasons) has only two sizes as obtained by the 18- and 22-screen sizes. The 16-size sublot can be recombined with the 18. On lot B, there appear to be three sizes, except that the quantity of sublot from screen 24 was only 6 pounds, whereas size 22 was 158 pounds. Although there is a real difference in seeds per pound, there may be too few seeds to keep separate. If combined with the sublot from screen 22, the planter will discharge one seed of sublot 24 for every 30 seeds of sublot 22. Such large ratios will overshadow any differences that might be seen by seed per pound alone. Thus, lot B also consists of only two sublots.

!n summary, from the standpoint of results in uniform density for the cost involved, no benefit is derived by keeping sized sublots separate if they are like the examples just cited. No benefit is obtained with any sublots that weigh less than 30 pounds, and that differ by less than 1,000 seeds per pound between sublots. These guidelines assume that reasonably precise seeders are being used. The less precise the seeder, the greater the minimum lot size should be, and the greater must be the seed per pound differences between sublots to realize differences in seedbed density.

3. Vigor, the elusive measurement

Vigor, according to Webster, means strength. The ability of a seed to produce a seedling under stress may be classified as vigor. This term differs from germination, which means the actual production of seedlings. Viability is the potential of seed to produce seedlings but does not provide a relationship to the effect of environmental stress on that potential production.

Germination tests are made under optimum and reproducible conditions so that each test relates to the last test. Germination is not determined under specific field conditions because those conditions may change by planting time.. Conversion of germination test results to field expectations is accomplished with a "survival" factor. This factor is based on actual field data collected over time. The factor usually falls between 65 and 80 percent in the South.

"Survival percent" is our attempt to quantify vigor. This term expresses the effect of environmental stress on the potential production of a seedling. According to the International Seed Testing Associa-

tion, "Vigor cannot be quantified because it is a concept . . . ." This statement is not totally true. Vigor is more than a concept, but few analysts know what they are trying to measure. If you had three lots of seed (A, B, and C) you might want to know which lot will give you the most seedlings.

In humans, we can perhaps understand vigor through the following example. A jogger and a nonjogger start out to walk up a steep hill. Part way up, the nonjogger has to sit down and rest because of exhaustion, while the jogger dances around, eager to go again. It is the effective energy of the jogger that relates to high vigor. There is energy to work against stress and to keep going. The exhausted nonjogger displays low vigor. If stress continues, the nonjogger may not complete the intended objective because of insufficient energy. The capacity for endurance can be increased through exercise and practice in humans, but for seed, germination is a single opportunity.

Seeds in a lot seldom all die at once. Rather, they age and die individually. Each lot or sample of filled seed consists of three components: dead, weak, and vigorous seed. A germination test identifies the percentage of dead seed, but does not identify which of the apparently vigorous seed are really weak, because even the weak seed germinate under optimum conditions. Data from studies and field plantings have shown that the percentage of weak seed in the total seedlot can be calculated by multiplying the percentage of germinating seed in the test by the percentage of dead seed. For example, a seedlot germinating 70 percent has 30 percent dead seed; therefore, 30 percent of the sound seed are weak. This calculation means that 21 percent (30 x 70 percent) of the seedlot is composed of weak seed. Seed in this 21-percent portion possess a broad array of weakness. The weakest seed of this portion will die under even low stress, and more will die as the stress increases. At maximum stress they will all die. At this point, even vigorous seed may be affected by extreme conditions. What we attempt to measure is the portion of the weak category that will die under various stresses such as drought, cold, or fungal infection. The problem is to predict what environmental stresses may occur. Because these potential stresses are not known, we only rate the vigor of a seedlot according to other lots or according to a series of specific stresses such as an array of temperatures.

In summary, many of the so-called vigor tests do not relate to vigor at all but rather are viability estimates. The only true vigor tests are those that either relate lots with similar germination rates to a given stress, or a single seedlot to varying environmental stresses. A measure of vigor to temperature may be quite different from a measure for drought. This complication makes vigor measurements difficult! Thus, there is no direct measurement of vigor; only a relative measure in the comparison of two or more lots or two or more stresses.

4. Impact damage, the quiet death of a seedlot

Tree seed are at their maximum potential viability at maturation. This potential may be reduced by environmental impacts, human intervention, or natural aging.

Viability of seed is affected by many factors. Mechanical damage allows organisms and moisture to readily enter the seed and initiate deterioration. High temperatures may denature enzymes or desiccate tissue, which also leads to a catastrophic death. Elevated moisture contents promote chemical change and support cell division at room temperatures. At cooler temperatures, the heat of respiration usually leads to deterioration. And then there is the natural aging process.

Cell division cannot take place during dry storage. Metabolism is also reduced to a very low level. However, a large amount of cell membrane damage does occur, which leads to a slow death known as aging. The rate of death due to aging is related to seed moisture content and existing temperatures.

Aging is increased by increases in both temperature and seed moisture content.

The least observed--and yet one very common--cause of seed loss is the subtle "quiet death" from impact damage. This kind of damage is similar to the bruise you might experience if you were to trip and fall on a concrete floor. A slight redness immediately gives way to a darkening the next day and eventually a black and blue spot. The bruise on the seed is usually insignificant at the time of processing and will not affect germination at that time. After a short storage period, the extent of damage is observed in abnormal germination. The injury leads to reduced germination, which gets worse with time. The loss in germination is caused by deterioration of individual seeds and can be monitored through germination tests.

Impact damage is very difficult to identify in a single test, but quite easy to recognize in a series of tests over time. The first indication is an increased number of seedlings with endosperm collars.

Impact damage occurs when the seed bounces off elevators and machine parts. Each contact with a solid surface bruises a few cells or a small amount of tissue. Damage is only evident when the bruises are either numerous enough or large enough to affect germination. Impact damage increases as the number of contacts rises and with seeds that have a reduced moisture content. That is, a dry seed is more subject to impact damage than is a moist seed. Increased moisture provides some cushion against the impact.

In summary, seed viability can be improved by not only correction of the visible damages, but also by reducing the "slam-bang" of fast operations. Making seed processing more of a fluid operation, that is, a smooth flow, can increase seed germination by eliminating impact damage.

Collection Procedures Affect Germination of Northern Red Oak (*Quercus rubra* L.) Acorns

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*Specifics of acorn collection procedures affect germination in northern red oak (*Quercus rubra *L.) and can be important in obtaining a sufficient acorn supply. Tree-collected acorns had better germination than ground-collected acorns. Acorns that sank during water flotation had a high germination percent regardless of whether they were tree or ground collected. Tree-collected floaters did not significantly lower germination than either tree- or ground-collected sinkers. Ground-collected floaters had the lowest germination. The original position of acorns in the tree crown had no significant effect on germination. Water flotation is recommended for all acorn collections.* Tree Planters' Notes 37(3):812; 1986.

Acorn crops differ greatly from tree to tree, from location to location, and from year to year (8). Add to this the problems of long-term storage for red oak acorns (10), and the specifics of acorn collection become important in obtaining an acorn supply sufficient for forestry purposes.

We studied the viability of acorns collected from the ground and from the tree in one study and from several positions within a tree in another. We also tested water flotation as a method of determining viability. Our findings should be helpful to foresters and nurserymen who wish to propagate oak, particularly in poor seed years.

Although mature acorns are most commonly collected from the ground after they fall, they can be collected after manual or mechanical shaking or they can be picked off the tree from a hydraulic lift. After collection, acorns are commonly tested for soundness by water flotation (1, 6, 7). Floating acorns are usually considered unsound and discarded. Although this simple float test has been used for years, to our knowledge it has not been tested experimentally.

Materials and Methods

Experiment 1. On September 28, 1982, we collected acorns from a single northern red oak tree in Oneida County near Rhinelander, WI. Acorns were mature and were beginning to fall from the tree. We collected newly fallen acorns from the ground, and then spread tarpaulins under the tree and shook acorns from the branches. Acorns were segregated into lots according to collection procedure and tested by water flotation. The presence of intact acorn cups was also noted. Not all acorns collected from the tree had intact cups; all acorns collected from the ground with cups intact floated in water. Five categories were recognized:

1. Ground-collected floaters with cups (GFC).
2. Ground-collected floaters without cups (GF).
3. Ground-collected sinkers (GS).
4. Tree-collected floaters (TF).
5. Tree-collected sinkers (TS).

Acorns were rinsed in captan fungicide to retard mold and then their surfaces were air dried. Lots of 50 acorns were stored in 4-mil polyethylene bags at 4 °C for 95 days, because red oak acorns require cold stratification to break embryo dormancy (5). Acorns were then removed from the cooler, allowed to warm to room temperature, and soaked in water overnight.

Germination was determined in January 1983 in a greenhouse bench filled with a 3:1 mixture of coarse perlite and sand (about 10 centimeters deep). Acorns were planted about 2 centimeters deep at 7.5 by 10 centimeters spacing, and the seedbed was maintained at 40 percent moisture content (ovendry basis) at 22 °C. Artificial light (150-watt flood lamps) was provided daily from 8 a.m. to 4 p.m.

Experiment II. On September 7, 1983, we collected acorns with the aid of a hydraulic lift from another northern red oak tree near Rhinelander, WI. Acorns were collected from branches at four different heights in a 16-meter-tall tree: 1) 16 meters (top), 2) 12 meters, 3) 8 meters, and 4) 4 meters (bottom). Acorns from each stratum were kept separate and then floatation-tested. All sinking acorns were bagged and stored as in experiment I for 118 days.

Acorns were planted in January 1984 as in experiment I. The germination bed was lighted artificially for 16 hours per day from 6 a.m. to 10 p.m. and was watered with an intermittent mist system (i.e., 2-second misting every half hour).

Germination. Emergence of the epicotyl from the seed bed was used as an indicator of germination (3, 5). (Emergence percent is considered an indicator of germination percent throughout the paper.) Germinating acorns were counted and recorded three times a week for 6 to 7 weeks. Germination percent and peak value were used to quantify germination success. Peak value was proposed by Czabator (4) to express both the speed and completeness of seed germination. Peak value (PV) is equal to the maximum cumulative germination percent divided by the number of days from sowing.

Because germination percent data do not usually exhibit a normal distribution, these data were transformed with arcsine v % for analysis (9). Peak values were not transformed. Analyses of variance were conducted on transformed data in the case of germination percent and on raw data for the peak values. Linear contrasts (9) were used to compare treatments at weekly intervals over the duration of the experiment (table 1).

Table 1—*F-tests of significance of linear contrasts from analysis of variance of percentage germination data from northern red oak acorns at 5 weeks after planting (experiment I)*

Source of variation	Degrees of freedom	F-test	Significance[1]
Treatments	4	31.4	0.01
Ground-collected vs tree-collected acorns	1	6.4	0.05
Ground-collected sinkers vs floaters	1	17.8	0.01
Tree-collected sinkers vs floaters	1	2.0	NS
Cups vs no cups	1	99.2	0.01

[1] Transformed percentage germination data.

Table 2—*Germination rates of northern red oak acorns collected in 1982 and 1983 in Oneida County, WI*[1]

Treatment	Peak value ± SE
Experiment I	
Tree-collected sinkers	4.1 ± 0.4 a
Ground-collected sinkers	3.4 ± 0.5 a
Tree-collected floaters	3.3 ± 0.5 a
Ground-collected floaters	1.6 ± 0.3 b
Ground-collected floaters w/cups	0.1 ± 0.1 b
Experiment II	
16-m-high branches	1.9 ± 0.3 a
12-m-high branches	1.9 ± 0.2 a
8-m-high branches	1.6 ± 0.1 a
4-m-high branches	1.8 ± 0.2 a

[1]Peak values calculated according to the methods of Czabator (*4*) and Bonner (1984). Peak values for each experiment followed by the same letter are not significantly different at the .05 probability level.

Results and Discussion

Germination percentages of northern red oak acorns varied greatly with acorn collection procedures and with water flotation (fig. 1). After 5 weeks, germination in experiment I had stabilized and ranged from 2.5 to 85.0 percent. Tree-collected acorns had a significantly higher germination percent than ground-collected acorns (table 1). But "sinkers" had a high germination percent regardless of where they were collected. Although tree-collected sinkers had the highest germination percent, the difference in germination percentage was not significantly different from ground-collected sinkers (fig. 1). Tree-collected sinkers did, however, have a peak value higher than the ground-collected sinkers (table 2), indicating that they germinated more rapidly (4).

Surprisingly, the germination rate of tree-collected floaters was over 70 percent and was not significantly different than the rates for ground-collected sinkers or tree-collected sinkers. Ground-collected floaters had a germination percent and peak value much lower than the ground-collected sinkers and

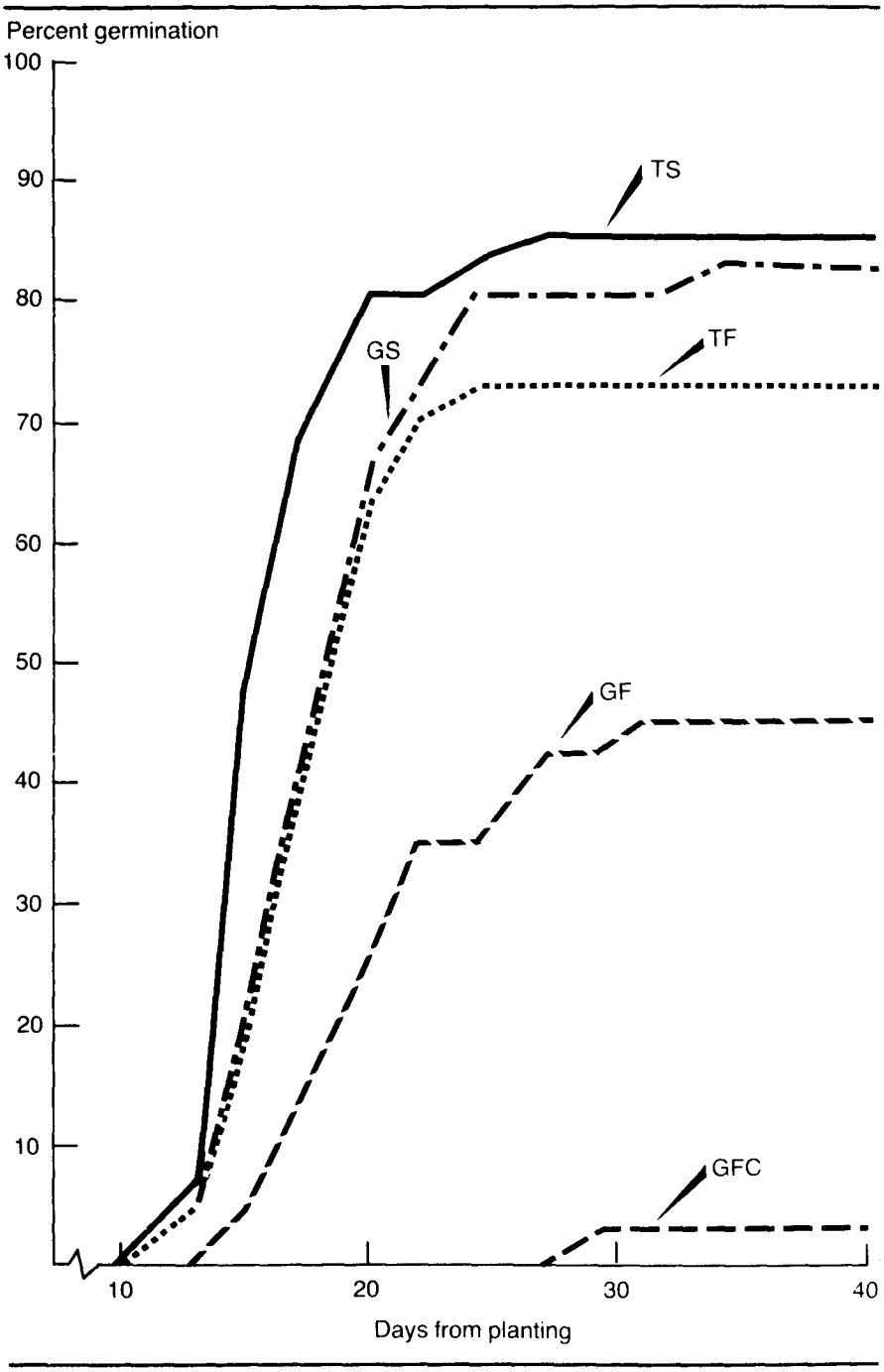

Figure *1-Percent germination of northern red oak acorns over time after various collection procedures and water flotation. TS = tree-collected sinkers, GS = ground-collected sinkers, TF = tree-collected floaters, GF = ground-collected floaters, and GFC = ground-collected floaters with cups. Acorns were collected in Oneida County, WI, in 1982.*

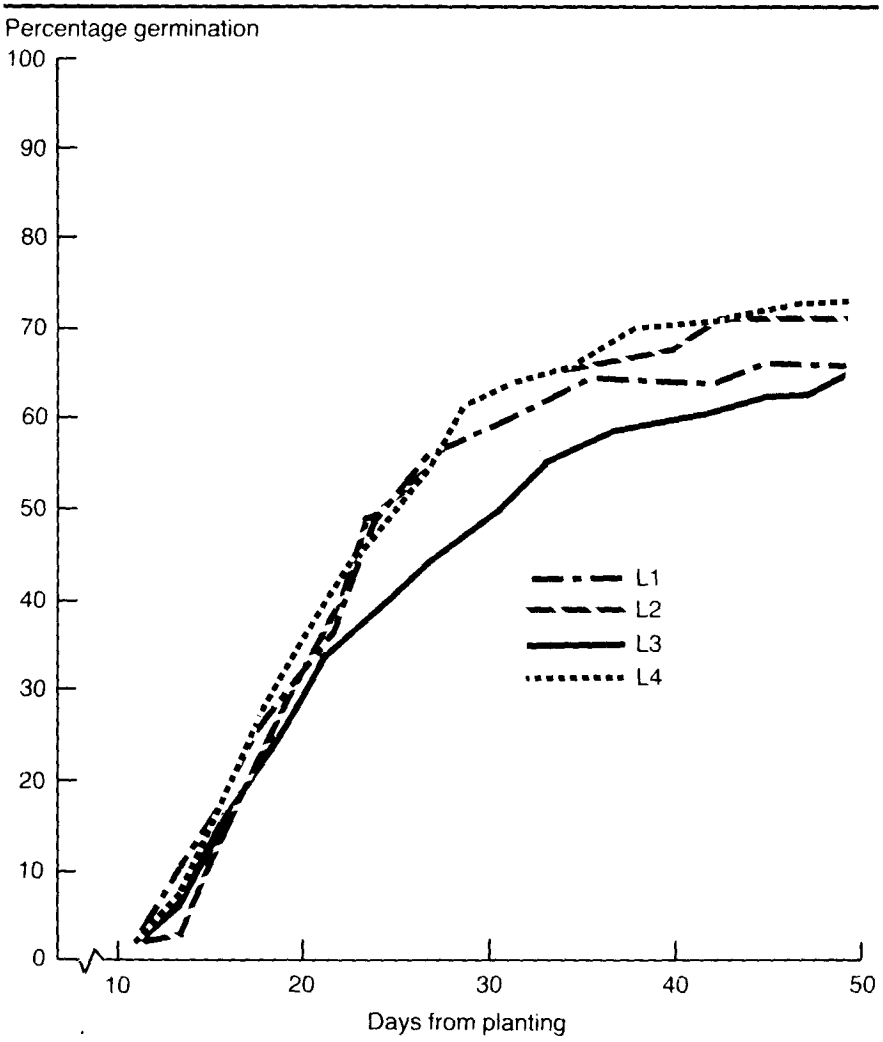

Figure 2—*Percent germination of acorns collected from branches at four heights in a northern red oak tree. L1 = 16-meter-high branches (top); L2 = 12-meter-high branches; L3 = 8-meter-high branches; and L4 = 4-meter-high branches (bottom). Acorns were collected in Oneida County, WI, in 1983.*

even the tree-collected floaters. The fact that tree-collected floaters germinated better than ground-collected floaters is important, because it means that foresters have an additional source of viable acorns, particularly in poor seed crop years. To our knowledge the distinction between tree and ground floaters has not been made previously.

Ground-collected floaters without cups had a much lower germination percent (< 50 percent) and germinated much slower than either the sinkers or the tree-collected floaters (table 2). Ground-collected floaters with cups germinated poorly, and are not likely to germinate in either a natural or artificial environment.

Acorns in 1983 had lower germination percents (fig. 2) and lower peak values (table 1) than acorns from the first study tree in 1982. Despite the fact that all acorns in experiment II were tree-collected sinkers, their germination percent ranged from only 65 to 73 percent in 7 weeks which was somewhat lower than in 1982. However, location within the tree made no significant difference in either germination percent or peak value (fig. 2; table 2). It should be noted that this was a vigorous, young tree growing in a mixed hardwood stand. Older trees growing under different stand conditions may not produce such a uniform crop of acorns.

The reason for the lower germination percents and peak values in the second experiment may be the fact that the acorns were collected from a different tree, during a different year. Including more trees in the study may have helped answer this question. However, this is an example of the kind of variation that foresters who collect acorns routinely face due to the uncer-

tainty of acorn crops from tree to tree and from year to year (8). The acorns in experiment II may have been collected slightly before their maturation date, because many were just beginning to turn brown and had not yet separated from their cups (2).

Conclusions

Our findings should be helpful to foresters and nurserymen who wish to propagate oak, particularly in poor seed years. Acorn collection and handling procedures can affect both the percentage and rate of germination of northern red oak seed. Tree collection of acorns can be made from all portions of the red oak crown, and acorns should be collected after they lose their green color just before separating from the cup. Tree collection is recommended for best germination.

Acorns that sink during water flotation are the most viable regardless of whether they are collected before or after falling from the tree. Thus, we recommend water flotation for all acorn collections. Surprisingly, tree-collected floaters without cups also germinate well, but ground-collected floaters without cups do not. Ground-collected floaters with their cups intact have little or no germination capability.

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The Aquarium Tester--A Fast, Inexpensive Device for Evaluating Seedling Quality

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*Materials and methods for a hydroponic test of root growth potential are described, and the technique is used to evaluate Douglas-fir (*Pseudotsuga menziesii *(Mirb.) Franco) seedlings that were outplanted in the southern Cascade mountains.* Tree Planters' Notes 37(3):13-16; 1986.

The Medford BLM District has been evaluating a method of hydroponically determining the quality of its lots of lifted Douglas-fir seedlings prior to planting. With this method, samples of at least 15 seedlings from each lot to be tested are removed from the newly delivered bags and boxes and the roots placed in simple 10-gallon aquariums (fig. 1). After 14 days, new root growth is readily apparent and measurable, and the quality of the stock can be evaluated by counting the number of new root tips 1 centimeter and longer.

The significance of this aquarium root growth was evaluated last summer in the field in a formal research study in which the seedling survival of nursery lots was compared with contrasting levels of seedling root growth. The first year results indicate that a positive and notable correspondence exists between the number of new roots produced in 14 days in the aquarium test and field survival of seedlings from the same lots. An inexpensive practical method to help users evaluate the quality of their seedlings prior to outplanting is outlined in the article that follows, along with the results of the research study we implemented.

Figure 1—*Aquariums with aerators and seedlings installed.*

Constructing the Aquarium Tester

Materials for the construction of one aquarium tester can be purchased for under $65.00 (table 1). Access to a band saw and drill press reduces labor and construction time. If these tools are not

Table 1—*Materials for the construction of the aquarium tester*

Materials	Quantity	Approx. cost ($)
10-gallon glass aquarium	1	15.00
¼-inch-thick Plexiglas top (12 by 20 inches)	1	9.00
Air pump	1	6.00
Air pump tubing per foot	5	.50
Aerator stone	1	1.00
#11½ black rubber stopper	15	15.00
Aerosol paint can	2	3.00
Glass tube aquarium heater	1	5.00
Total cost		62.50

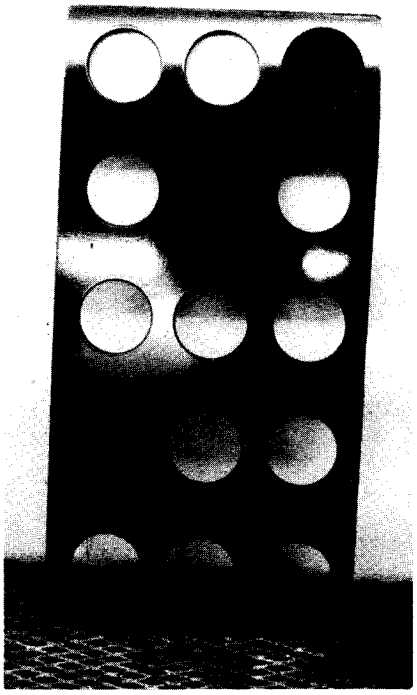

Figure 2—*Painted Plexiglas aquarium cover with 2¼-inch holes and rubber stoppers.*

available, a hand-held half-inch drill, a vise or clamps, a circular or band saw, a $2^1/_4$ -inch hole saw, and a hacksaw will suffice.

Obtain a piece of Plexiglas approximately 12 by 20 inches and trim with the band saw or circular saw to fit the inside lip at the top of the tank (fig. 2). Do not use plywood; it warps, allowing light to enter the tank easily. Using the hole saw, cut up to fifteen $2^1/_4$ inch holes in which to insert rubber stoppers. A half-round file may be needed for smoothing any rough edges. At some point on the edge of the lid, cut or drill notches for the air tube and aquarium heater to enter the tank. The top should be painted black to keep out light. Lightly sand the Plexiglas top to help paint adhere.

Clean the outside glass surfaces of aquarium thoroughly before painting so that paint will adhere. Black electrical tape may be used to cover seams and missed spots. Take care to ensure that paint does not come in contact with the underside of the lid or inside of the aquarium, for toxic substances in the paint may harm the seedlings.

Turn the tank upside down and paint it. Cut a line in the stoppers from the outside edge to the center hole so that the seedlings can be inserted.

Once the paint is dry, fill the tank with fresh water and connect the air pump. A small air pump has the capacity to aerate one tank. Use fresh water in a thoroughly sterilized apparatus (liquid bleach works well) each time a test is run. Attach the aquarium heater and set it to maintain a minimum water temperature of 68 to 70 °F at least 1 day prior to placing seedlings in the tank.

Be careful not to damage the bark or cambium layers when inserting the seedlings in the stoppers (fig. 3). Tight center holes should be enlarged, and seedlings smaller

Figure 3—*Plexiglas cover with rubber stoppers and seedlings installed.*

than the holes can be held in place with cotton wool.

After 14 days in the aquarium, remove the seedlings and clip all new white roots over 1 centimeter long. Roots can be quickly removed with clipper or fingernail. Count and measure roots from all seedlings and divide by the number of test seedlings to establish the root growth class for the seedling lot (table 2). Although correlation between these classes and subsequent seedling performance is tentative, planting recommendations are listed in table 2.

Table 2—*Root growth classes and subsequent performance*

Class	Description*	Planting quality
0	No new growth	Dead or very poor—do not plant
1	Some new roots, none over 1 cm long	Dead or very poor—do not plant
2	1 to 3 new roots over 1 cm long	Poor to fair—plant on low-stress sites only
3	4 to 10 new roots over 1 cm long	Good quality—plant on typical new sites
4	11 to 30 new roots over 1 cm long	Excellent—plant on droughty sites
5	30+ new roots over 1 cm long	Superior—plant on toughest sites

*From Burdett (*1*).

Root Growth Potential Test

Thirty Douglas-fir seedlings produced from certified seed of the same seed source but grown at two different west Cascade nurseries (15 seedlings from each) were tagged and randomly placed in two aquarium testers on April 5, 1985. Root growth was visually evaluated 2 weeks later (fig. 4), but seedlings were left in the tanks for an additional week (for a total of 3 weeks) before the final evaluation and clipping on April 26. Little or no root growth was noted after the previous inspection.

The evaluation indicated that the seedlings produced by nursery A had a range of 1 to 4 new root tips that were 1 centimeter and longer per seedling, with an average of 2.33 roots per seedlings; this corresponds to root growth class 2--poor to fair. For nursery B, the number of new roots ranged from 1 to 16 per seedling, with an average of 7.4. This corresponds to root growth class 3-good quality.

Figure 4—*Douglas-fir seedling roots after 14 days in tank. Class 4 = 11 to 30 new roots measuring over 1 centimeter.*

Outplanting Trial

Four hundred 2-0 bareroot seedlings from nursery A and nursery B (200 each) were planted by skilled planters on April 4, 1985, at a test site in southern Cascade mountains north of Butte Falls, Oregon. The planting layout followed a randomized complete block design with four replications on a tractor-scarified and ripped south-facing clear-cut (slope less than 30 percent) at 3,240 feet in elevation. The site had been operationally planted the previous year with survival exceeding 90 percent. No gopher damage nor deer browsing was observed on the previously planted seedlings, and very little grass was present, but heavy infestations of bull thistle developed in the summer of 1985. This competition may have affected variation in survival among replications, making detection of the effects of seedling quality on survival more difficult. Survival was measured twice during 1985; in August and

in late October. Percent survival of seedlings from nursery A was 81 percent in August and 50 percent in late October as compared to nursery B with 90 percent and 66 percent at those times.

Discussion

In this study, differences in seedling root growth for the two nursery lots were congruent with first-season seedling survival in the field. Seedlings with the lower root growth potential, as measured by the aquarium tester, performed more poorly after outplanting. Observations of operationally planted seedlings from the two nursery lots involved corroborates the root growth and field survival test; the seedling lots with the lower root growth survived less well. In addition, the general appearance and condition of the surviving seedlings at the end of the first growing season was notably better for the seedling lots that tested better in the aquariums.

Conclusion

Determining the root growth potential of Douglas-fir seedlings hydroponically may have some potential as a predictor of seedling quality prior to planting. Articles and publications by Ritchief (5), McCreary and Duryea (4), Stone and Jenkinson (8), and Burdett (1) indicate that root growth potential is positively correlated with first-year survival and growth. Using this method, measurable results may be obtained in 14 days, compared to the 25- to 45-day period required by the growth chamber method of potting seedlings and evaluating subsequent bud break and flushing (2).

Other advantages of this method are that no growth chamber is necessary, root growth is visible, roots are easily accessible and easily measured, and there is no loss of new root tips in the growing medium. Further testing is necessary to more precisely define the relationship between water temperature of the aquarium and the minimum time before measurement, the best minimum length of new root tips to count, and the closeness of the relationship between the classes and field performance of the seedlings. With development of the aquarium tester, however, foresters and other nursery users, with minimal investment, can begin to evaluate their seedling stock while it is still in the cooler, and also help answer some of the questions posed above.

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Nutrient Concentration Effects on *Pisolithus tinctorius* Development on Containerized Loblolly Pine (*Pinus taeda* L.) Seedlings

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A trade-off between seedling size and degree of mycorrhizal infection needs to be considered when determining the rate at which to fertilize containerized seedlings infected with ectomycorrhizae. Tree Planters' Notes 37(3):17-22; 1986.

Ectomycorrhizae can increase forest tree survival and growth under many different site conditions (11). Mycorrhizae increase tree root surface area, increase the absorption of water and nutrients, and can exploit forms of phosphorus (P) unavailable to nonmycorrhizal plants (1). *Pisolithus tinctorius* (Pers.) Coker & Couch is a fungus capable of forming ectomycorrhizae on trees growing on acidic, droughty, and infertile soils. It has been used successfully for improving the performance of pines on reclaimed surface mines (6) and on clay soils in North Carolina and Georgia (4).

Much work has been done on methods for inoculating pines with *P. tinctorius* basidiospores (5, 8, 9). Using spores is more convenient and less costly than inoculating with vegetative fungal mycelia. Marx and co-workers (7) found that ectomycorrhizal development was related to soil fertility, with nitrogen (N) and P being the most critical nutrient elements. At high N and P concentrations, *P. tinctorius* infection of loblolly pine appears to be reduced. Lower *P. tinctorius* infections coincide with lower levels of sucrose in the roots. On the other hand, Lamb and Richards (3) found that greater mycorrhizal infection of Monterey pine (*Pinus radiata* D. Don) and slash pine *Pinus elliottii* Engelm. on Australian soils occurred when P was applied. The objective of this study was to examine the relationship between nutrient levels and *P. tinctorius* ectomycorrhizal development on container-grown loblolly pine seedlings.

Materials and Methods

P. tinctorius fruiting bodies were collected in the fall from a 20-year-old loblolly pine (*Pinus taeda* L.) stand in Buchanan County, VA. Basidiospores were harvested, suspended in water, and added to vermiculite and peat (1 :1, v/v) that was being mixed in a cement mixer. Spores were applied at a rate equivalent to 250 grams per hectare. Spencer-Lemaire Rootrainers (Hillson model, 150 cubic centimeter per cavity) were filled with this mixture and two loblolly pine seeds of Virginia Piedmont origin were placed in each container. After germination, seedlings were thinned to one per container.

Four replications (eight seedlings per replication) of five nutrient solution levels (treatments) were used in this study (table 1). The five treatments consisted of a serial dilution of reagent grade chemicals. Molar ratios of 1 :1.2:1.1 :0.3 for $KN0_3$, NH_4S0_4, H_3PO_4, and Fe (as Greenol), respectively, were used to provide the various amounts of nutrients. A serial dilution was used to establish treatment levels so that the most concentrated treatment was 16 times as concentrated as the lowest fertilization rate (table 1). Nutrients were added in 15 milliliters of water every 2 weeks. Additional watering occurred on a regular basis.

Table 1—*Amount of nitrogen, phosphorus, potassium, and iron added every 2 weeks during the 20-week study period*

	Amount of nutrient (mg)			
Solution level	N	P	K	Fe
1×	0.25	0.16	0.21	0.09
2×	0.50	0.32	0.42	0.18
4×	1.00	0.64	0.84	0.36
8×	2.00	1.28	1.68	0.72
16×	4.00	2.56	3.36	1.48

After 20 weeks, seedlings were harvested. The degree of mycorrhizal infection was calculated as the number of individual short roots colonized, divided by the total, and expressed as a percentage. Roots and shoots were separated at the root collar, dried to a constant weight at 65 °C, and weighed. After weighing, needles were stripped from the stems and composited by replicate for foliar N and P analyses. Foliar N was determined by the Kjeldahl technique (2). Phosphorus was extracted with 6 N HCl from 0.5 gram of tissue, following dry-ashing at 450 °C. Phosphorus was determined by the Murphy-Riley ascorbic acid technique (13). Regression techniques were used to analyze the data (12).

Results and Discussion

Fertilizer concentration had a significant effect on degree of infection, shoot weight, root weight (figure 1) and on foliar N and P concentrations (figure 2). The highest rates of fertilizer resulted in larger seedlings, but mycorrhizal colonization was greatest at the lower rates. Maximum root system colonization was about 30 percent, which decreased to about 10 percent at the highest fertilizer level.

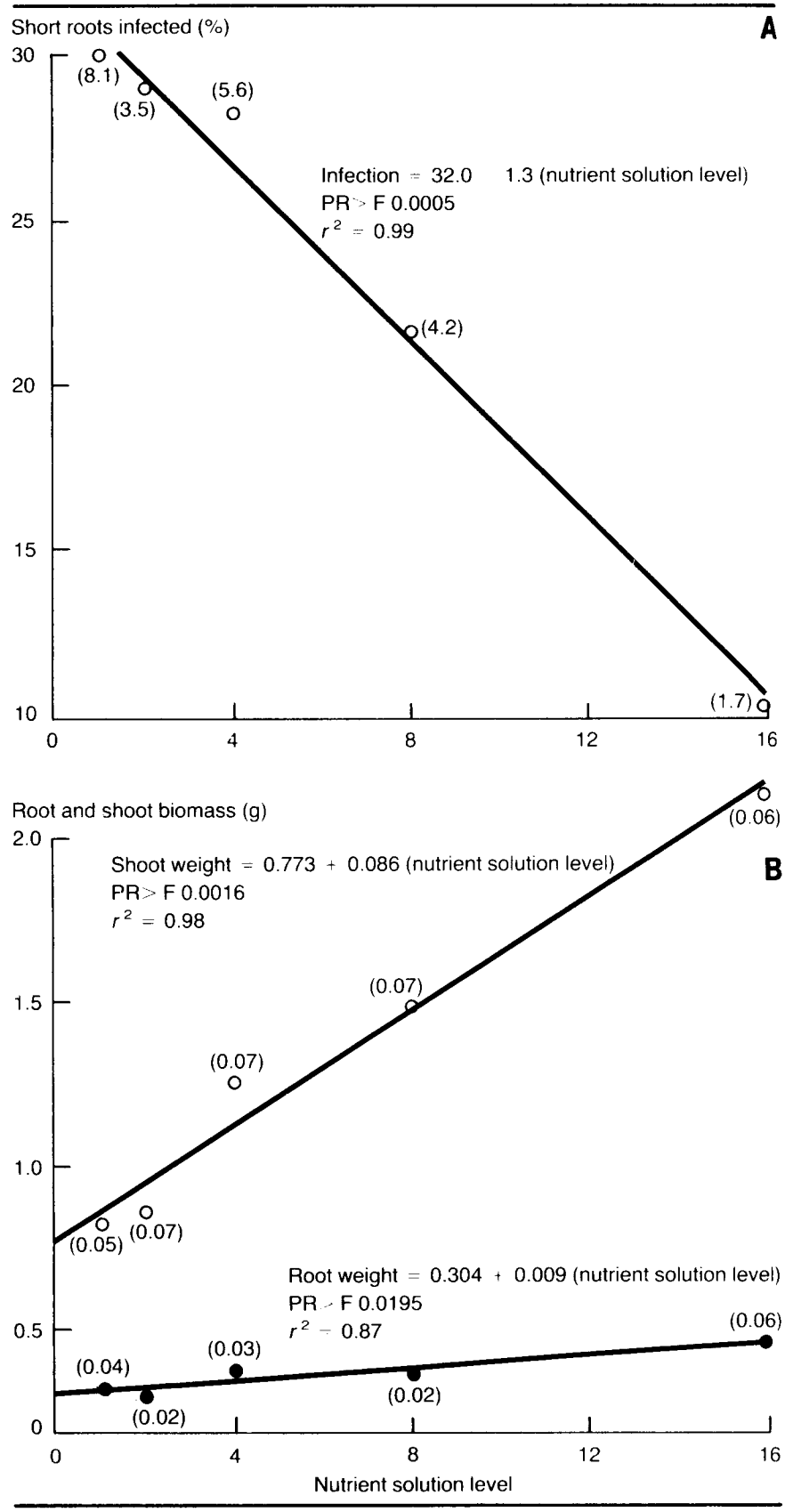

***Figure 1**-Relationship between mycorrhizal infection (**A**), seedling biomass (**B**), and nutrient solution level. Numbers in parentheses are standard deviations.*

Foliar nutrient levels increased with fertilizer rate (figure 2). In the most concentrated treatment, foliar N and P levels were 1.02 and 0.14 percent, respectively. Although the N/P ratio (1.56 milligrams per milligram) in the nutrient solution was greater than the N/P ratio (1.21) used by other researchers (9, 10), there seemed to be insufficient N even at the highest treatment level. Nitrogen is generally considered deficient when foliar levels are below 1.2 percent, whereas 0.1 percent is a commonly accepted critical level for P (14).

There were also significant relationships between foliar nutrients and seedling biomass and infection (figures 3 and 4). Shoot weight increased but root infection decreased with increasing foliar N and P levels. Seedling size continued to increase as foliar P levels rose above 0.1 percent. This can be explained by the fact that N was limiting but P was available in sufficient quantities. Additional increments of N and P then resulted in luxury consumption of P, while seedling growth was still responding to added N.

Although root weight was used as a measure of root size, an estimate of total root length or surface area would have been more meaningful. There were distinct morphological differences observed

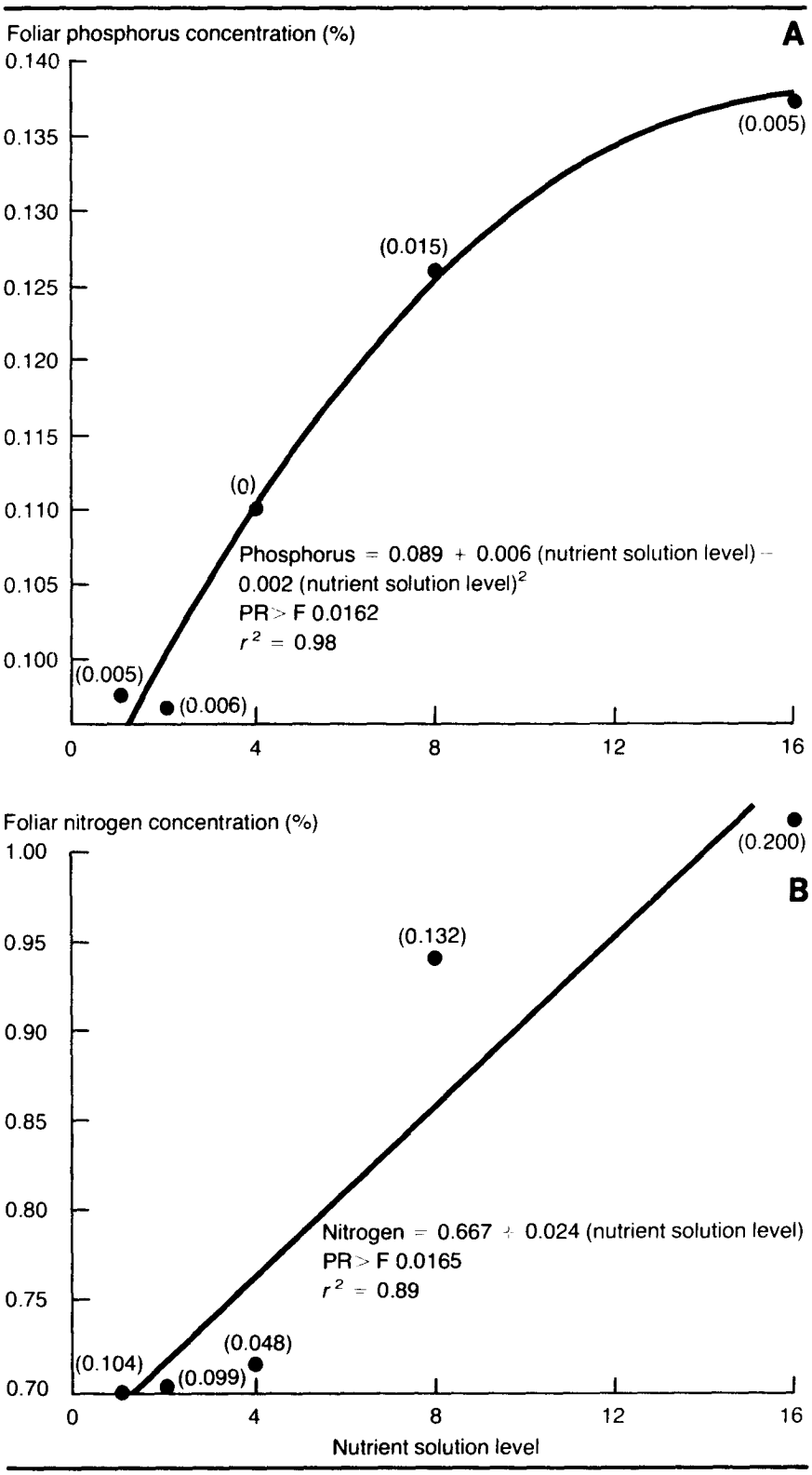

Figure 2—*Relationship between foliar phos phorus (**A**) and nitrogen (**B**) and nutrient so lution level. Numbers in parentheses are standard deviations.*

between root systems at different nutrient levels. Root systems of seedlings receiving the highest treatment were short and stocky. Although they weighed less, the root systems subjected to lower nutrient levels were longer, more fibrous, and had a greater degree of branching.

In order for seedlings to survive in harsh environments, they need an adequate root system to absorb moisture and nutrients. Seedlings receiving the greatest amount of nutrients in this study, although larger, could be at a disadvantage when outplanted. They would require greater amounts of moisture to meet the demands of their larger foliar biomass, but their root systems had a smaller surface area and less absorptive capacity. The likelihood that the smaller trees receiving the lowest levels of nutrients would be more successfully established is increased by the greater degree of mycorrhizal infection.

Conclusion

Although nutrients are necessary to develop healthy containerized seedlings, it appears that there is an optimal level above which additional nutrient supplies produce seedlings that may be more sensitive to drought and less able to

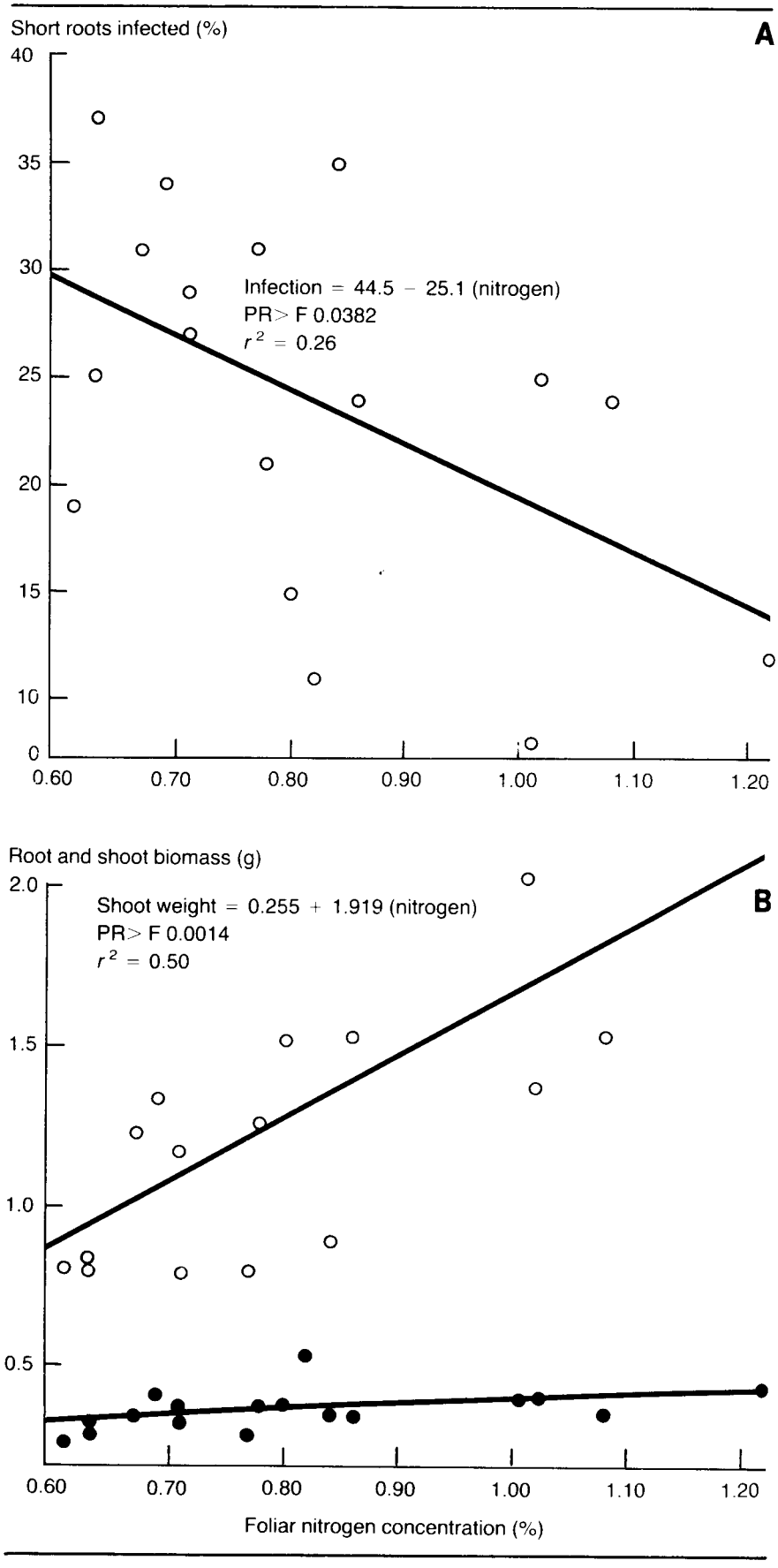

Figure 3—*Relationship between mycorrhizal infection (**A**), seedling biomass (**B**), and foliar nitrogen concentration.*

adapt to stress. Seedling size, root system morphology, and mycorrhizal colonization need to be optimized. An ideal fertilization program might be one that allows the seedlings to attain just enough N and P to reach foliar levels considered adequate for good growth. At higher levels, mycorrhizal infection is reduced and root systems undergo morphological changes resulting in smaller surface areas. In this study, level 4 x (1 .0 milligram N, 0.6 milligram P, and 0.8 milligram K) may represent the best level of nutrient supplementation because infection is still high and seedlings are significantly larger than those receiving lower levels of nutrients. Ultimately, seedlings should be outplanted to determine how these morphological and physiological properties affect establishment and early growth.

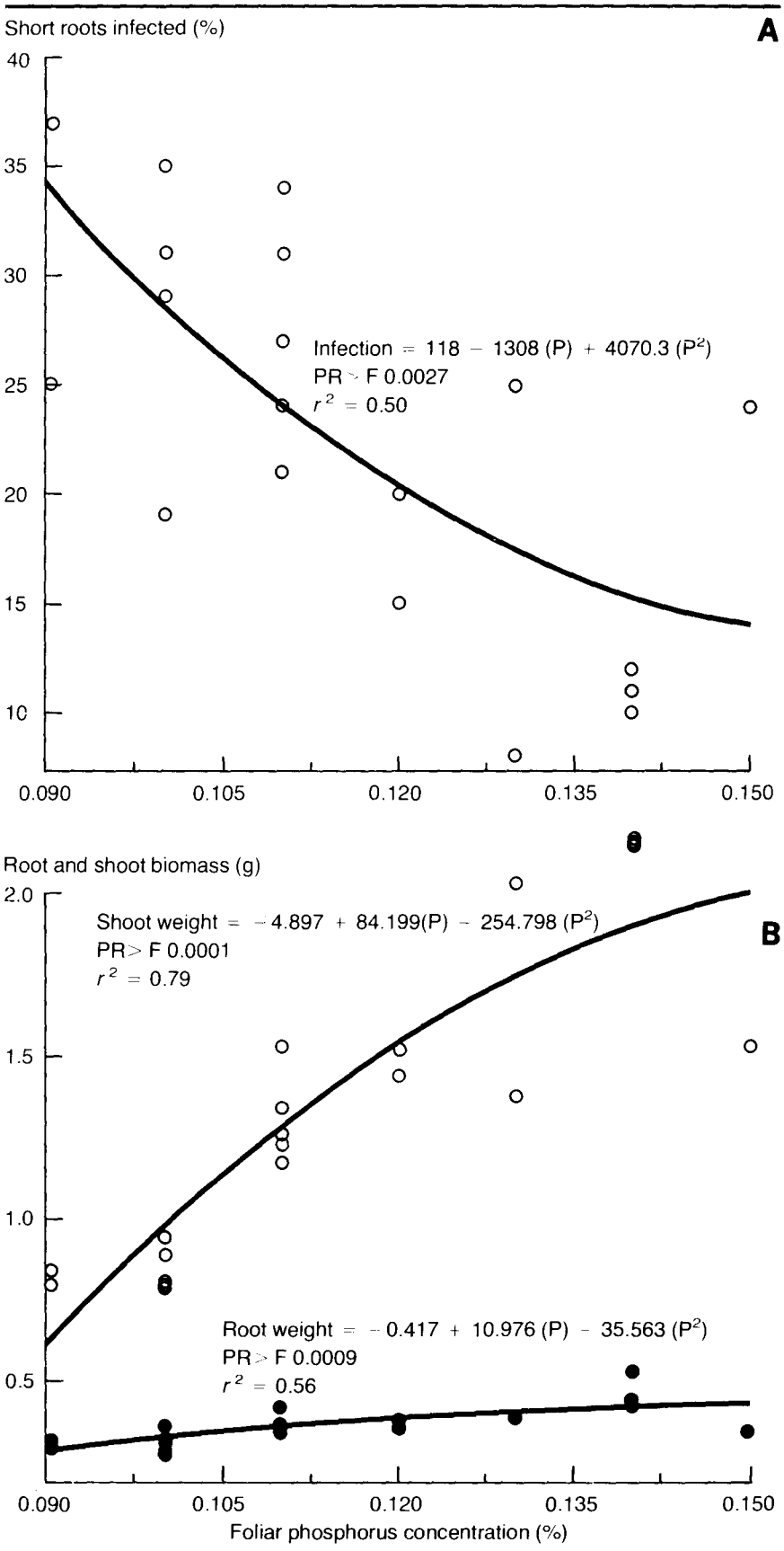

Figure 4—*Relationship between mycorrhizal infection (**A**), seedling biomass (**B**), and foliar phosphorus concentration.*

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Pine Plantation Survival Related to Calculated Moisture Deficits on the Huron National Forest (1929-1976)

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Soil moisture deficits are an important cause of seedling mortality on the sandy outwash plains typical of the Huron National Forest. Red and jack pine planting survival records from 1929 through 1976 were examined, and those years with two or more planting sites and consistent survival were chosen for study. Growing-season water deficit, expressed as the difference between precipitation and potential evapotranspiration, was significantly related to percentage survival using simple linear regression. Survival ranged from 30 to 95 percent, while moisture deficits ranged from + 0.40 to - 8.31 inches during the growing season. With a mean moisture deficit of - 3.82 inches during the growing season, the expected seedling survival is 80 percent. Based on available water contents in the sandy outwash soils, moisture deficits commonly exist during the growing season, and site preparation and planting practices should attempt to preserve surface organic layers. Tree Planters' Notes 37(3):17-22; 1986.

Obtaining acceptable survival of planted pine seedlings is often a challenge for regeneration foresters. Although competition with neighbors and pest attacks are the chief causes of mortality of older trees (2), a myriad of factors, including stock quality and handling, soil moisture and nutrient conditions, seed source, and pests influence planted seedlings (1). Proper attention to these details and appropriate planning for the reforestation effort have proven to be useful in reducing seedling mortality (5).

Of the many site factors that influence seedling survival, soil moisture is often critical. This fact has been well-documented for a number of tree species, including Douglas-fir (7), ponderosa pine (6), and loblolly pine (3).

The Huron National Forest has had an active reforestation program for over 55 years, and because of the sandy, droughty, glacial outwash soils that are common on the forest, much attention has been paid to the relationship between soil moisture and seedling survival. Several years ago an investigation was begun to determine if seedling survival could be adequately predicted by soil moisture or some other readily measurable climatological factor. A prediction equation would be useful to determine how much of the variation in seedling survival is attributable to soil moisture/climatological factors and how much remaining variation is attributable to other factors. Planting site management recommendations may be varied on certain sites to preserve organic matter, prohibit prescribed burning, or modify site preparation and planting practices.

Methods

First year planting survival records for the Huron National Forest were examined for the years 1929 through 1976. The survival data base consisted of those years for which there were two or more red pine and/or jack pine planting sites with consistent survival. The planting seasons selected represented 137 planting sites, 8,576 acres, and approximately six million seedlings.

Climatological data from the U.S. Department of Commerce, Environmental Science Services Administration was obtained for the study years, and potential evapotranspiration (PET) was calculated using the method of Thornthwaite (10). Thornthwaite's method for computing PET integrates the factors of vapor pressure, temperature, wind, humidity, evaporation, and transpiration and involves a series of calculations using monthly temperature values (9). Veihmeyer (11) presented Thornthwaite's equations as follows:

$$PET = 1.6 \cdot \frac{10\,T^{a}}{TE} \quad (1)$$

$$a = 0.000000675(TE)^{3} - 0.0000771(TE)^{2} + 0.01792TE + 0.49239 \quad (2)$$

$$i = T^{1.514} \div 5 \quad (3)$$

where:

PET = potential evapotranspiration (cm)

T = mean monthly temperature ºC)

TE = temperature - efficiency index, equal to the sum of 12 monthly values of heat index, *i.*

In order to compute PET for a given location:

- mean monthly temperature (T) is used to compute a heat index *i* using equation 3
- the heat indexes are summed over a year to obtain a temperature - efficiency index (TE)
- the temperature - efficiency index is used to compute the variable a using equation 2
- mean monthly temperature (T), temperature - efficiency index (TE), and the variable a are used in equation 1 to compute PET
- the PET computed by equation 1 may be adjusted for day-length and number of days per month (because the number of days per month varies between 28 and 31 and the number of hours of active evapotranspiration per day varies with latitude) (4).

A plot of monthly PET and precipitation is commonly used to display a water balance for a given location.

There is a water deficit when PET exceeds precipitation. If the soil moisture is depleted during this period, seedlings may die. Moisture deficits were calculated for the growing season months of May through August for each year and were used as an independent variable in a simple linear regression analysis with percentage seedling survival as the dependent variable.

Results and Discussion

Water deficit during the growing season and percentage seedling survival were significantly ($P<0.01$) related as follows:

$$\%\ \text{survival} = 99.1137 - 5.3836\ (\text{water deficit in inches}) \quad (4)$$

$$r = -0.795$$

$$SE = 12.2\%$$

Although many factors, such as competition for sunlight, insect and disease damage, limited soil nutrients, and poor stock quality and handling, also contribute to seedling mortality, calculated moisture deficit during the growing season was correlated with percent survival on the Huron National Forest (table 1). During 1934 the growing season moisture deficit was -8.31 inches, and during 1940 a moisture surplus of +0.40 inches occurred. On the average the moisture deficit during the growing season was -3.82 inches, however. Seedling survival ranged from 30 percent in 1933, when there was a moisture deficit of - 7.00 inches, to 95 percent in 1940.

Equation 4 is used to predict expected survival rates at varying moisture deficits. Table 2 displays the actual and expected survivals, as well as the relative occurrence of moisture deficits during the 47year study period. Eighty-four percent of the years had moisture deficits between 0.0 and -5.0 inches. Actual and expected survival rates were in reasonable agreement except at the - 7.0 moisture deficit, which had only a 30 percent seedling survival. For that year some factor other than moisture must have contributed heavily to seedling mortality. According to Ohms (8), a seedling survival rate of 70 percent is normal for the Lake States region, assuming good quality planting stock and proper planting procedures. A water deficit of about -5.0 inches should result in about 73 percent of seedlings surviving their first year. Water deficits below -5.0 inches may result in objectionable levels of mortality.

Thornthwaite's PET equation is useful for integrating the climatic factors of precipitation, temperature, wind, relative humidity, and evapotranspiration into a reliable

Table 1—*Descriptive statistics of regression data*

	Growing-season moisture deficit[1] (in.)	Percentage seedling survival
Mean	−3.82	80
Range	−8.31 to +0.40	30 to 95
Standard deviation	2.96	20

[1]Computed as the sum of the moisture deficits (precipitation − PET) for May through August

Table 2—*Actual and expected survival and relative occurrence during the study period for various moisture deficits*

Growing-season moisture deficit (in.)	Relative occurrence during study period (%)	Percent survival	
		Actual	Expected
−10	2	—	45
− 9	0	—	51
− 8	4	58	56
− 7	2	30	61
− 6	8	—	67
− 5	11	86	72
− 4	11	83	78
− 3	15	92	83
− 2	25	90	88
− 1	11	91	94
0	11	95	99
+ 1	0	—	100

index that is significantly related to seedling survival. In addition, PET can be used to indicate specific periods of moisture stress. The dominant soils planted to red and jack pine on the Huron National Forest are Typic Udipsaments of the Grayling, Graycalm, and Rubicon series. The average available water content for these soils is 5 percent, and the bulk density ranges from 1.3 to 1.7 grams per cubic centimeter for the surface 10 inches.

The available water holding capacity is computed by multiplying the percentage of available water content by the bulk density by depth of the horizon. Therefore, the available water holding capacity for the surface 10 inches ranges from 0.65 to 0.85 inches. The 47year mean daily PET's for the months of May through August for the Huron National Forest are 0.09, 0.14, 0.15, and 0.12 inches, respectively. Therefore, the available soil water would be depleted in May in 7.2 to 9.4 days, in June in 4.6 to 6.1 days, in July in 4.3 to 5.7 days, and in August in 5.4 to 7.1 days. Unless the top 10 inches of soil gets recharged during these time limits, the planted seedlings will experience moisture deficits with a resultant increase in mortality.

Summary

Agencies and organizations that are heavily involved in artificial regeneration recognize the importance of factors such as proper stock handling, correct planting practices, planting site condition, and soil moisture to early seedling survival. The simple linear regression equation presented here has proven useful in providing expected seedling survivals at various moisture deficits. If the survival rate is less than expected during a season with a relatively low moisture deficit, other factors may be implicated. Although foresters are unable to manipulate climatic conditions, and irrigation is infeasible, other site preparation practices such as preserving surface organic layers while removing competing vegetation may aid in reducing evapotranspiration losses.

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The Triple Bedformer--A Quick and Easy Method To Form Multiple Seedbeds

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Attaching three bedformers to a large three-point yoke allows for more efficient use of equipment, operator, and nursery ground in seedbed preparation. Tree Planters' Notes 37(3):32-34; 1986.

The formation of raised seedbeds is an integral part of the tree nursery sowing operation. Raised seedbeds help promote warming of the seedbeds during the initial germination of seedlings and increase drainage. Most nurseries in the Pacific Northwest form raised beds for these reasons (Oregon State University Nursery Survey). The importance of having straight and correctly laid out seedbeds is twofold. Without properly laid out seedbeds, there is a high risk of constricting one or two of the beds to accommodate the irrigation lines that define the unit. Also, straight beds enhance equipment operation such as drill sowing, root pruning, and fertilization. However, the primary purpose in the development of the triple bedformer was to expedite the sowing operation.

At the J. Herbert Stone Nursery, sowing is accomplished with two seed drills operating simultaneously. This requires a good deal of coordination between the tractor operators preparing the seedbeds and the two seed-drill operators.

Figure 1—*The trip bedformer. Note protruding rods from bedformers that mark the beds.*

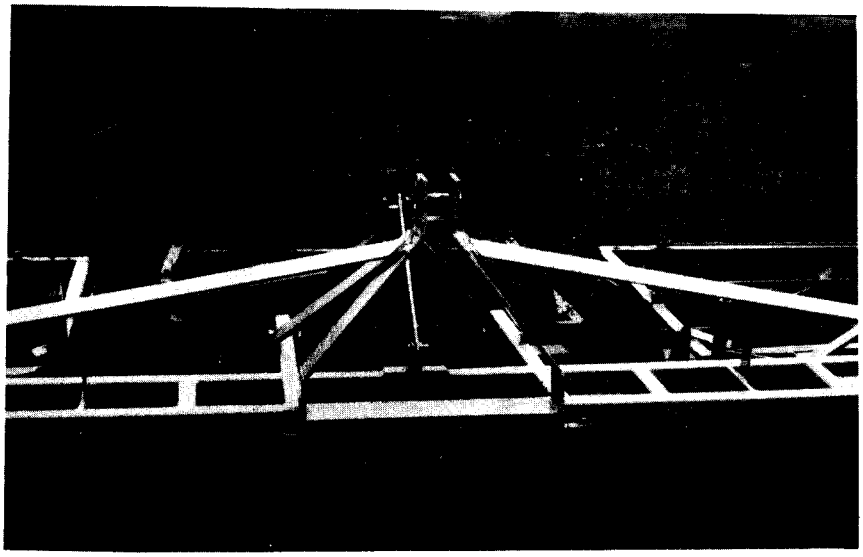

Figure 2—*Three-point hitch for triple bedformer.*

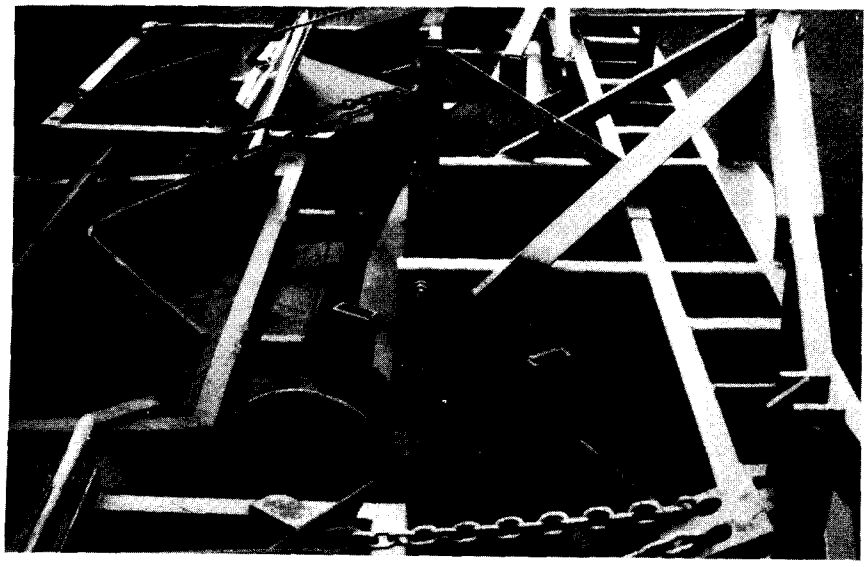

Figure 3—*Bedforming discs are offset.*

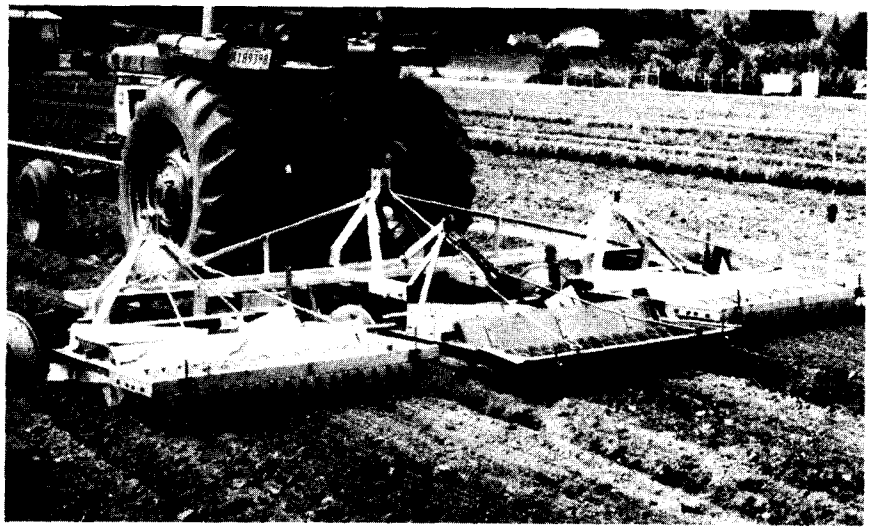

Figure 4—*Beds formed with triple bedformer.*

Therefore, a quick and efficient method of seedbed formation was of paramount importance.

Methods

Nurseries have used many different methods to form and mark beds, many of them homemade. Some nurseries rely on string lines, tractor-mounted bed markers, experienced tractor operators with "calibrated eyeballs," or sophisticated electronic equipment such as a laser. However, all of these methods have a common factor: they form only one bed at a time. In order to reduce the time required in seedbed preparation, personnel at the J. Herbert Stone Nursery developed the triple bedformer to form three seedbeds in one tractor pass.

Utilizing two Whitfield and one Larchmont bedformers, J. Herbert Stone Nursery personnel built and tested a triple bedformer (fig. 1). Bedforming implements as a rule are not extremely heavy, but there was some concern about the combined weight of three formers in addition to the newly constructed three-point yoke (fig. 2). Testing alleviated this concern. The middle former had to be placed further back than the outside two because the soil-scraping discs interfered with each other (fig. 3). The three

bedforming implements were attached to the yoke by means of individual three-point hookups welded on the main yoke. Guide markers were attached to the rear of each single implement.

A 40-horsepower Ford tractor used for the trial runs had no difficulties with lifting or pulling the triple bedformer. With adequate bracing and reinforcement, the implement was strong enough to perform well under field conditions (fig. 4).

Discussion

Multiple bedforming offers several advantages to single bedforming. Since only two passes are necessary to form an entire unit as opposed to six, an immediate savings of 66 percent is realized. Soil compaction is also reduced. The seedbeds formed with the triple bedformer are more straight and level than those formed by individual passes. Bed height is more uniform and path width is constant. Time spent bedforming was greatly reduced and string lines and row workers were eliminated, because irrigation pipelines served as guides.

Seed Stratification Treatments for Two Hardy Cherry Species

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*Seed of Mongolian cherry (*Prunus fruticosa *Pallas) germinated best after 30 days of warm plus 90 days of cold stratification. Amur chokecherry (*Prunus maackii *Rupr.) was best after 30 days of warm plus 60 days of cold stratification. Longer stratification periods resulted in germination during storage.* Tree Planters' Notes 37(3):3538; 1986.

The genus *Prunus* contains many native and introduced species that are hardy in the Northern Plains and are used for shelterbelt, wildlife, reclamation, and ornamental plantings. Two relatively recent introductions from Asia are Mongolian cherry (*Prunus fruticosa* Pallas) and Amur chokecherry (*Prunus maackii* Rupr.).

Prunus fruticosa is placed in the subgenus Cerasus. It ranges from central and eastern Europe to Siberia and is rated as zone III in hardiness (3). It is a suckering, spreading shrub that grows to 2 meters in height and will form dense thickets. The leaves are a dark glossy green. The tart, dark red fruits measure about 1 centimeter in diameter and are utilized by wildlife and humans. Mongolian cherry may be used in outside row plantings in shelterbelts, recreational plantings, and wildlife plantings.

The seed-propagated selection 'Scarlet' Mongolian cherry (figs. 1 and 2) has recently been released by the USDA Soil Conservation Service for conservation purposes in the Northern Plains (4).

Prunus maackii is placed in the subgenus Padus. It ranges from Manchuria to Korea and is rated as zone II in hardiness (3). It is a nonsuckering tree that grows to 15 meters in height. Its leaves are dull green. The dark purple fruits are borne in racemes and are utilized by wildlife. Amur chokecherry is often planted as an ornamental because of its copper-colored, flaking bark, but it could also be useful in wildlife and recreational plantings.

Information regarding seed propagation of these two species is limited. Initial late fall nursery seedings resulted in minimal germination the following spring but in satisfactory germination the second spring after planting.

Seed of *Prunus* species require a period of after-ripening to aid in overcoming embryo dormancy (2). Several species require a warm stratification period followed by cold stratification. It was believed that *P. fruticosa* and *P. maackii* might benefit from this. Researchers at the Morden Manitoba Experimental Farm found that germination of *P. fruticosa* seed may be affected by the time of fruit

Figure 1—*Growth form of 'Scarlet' Mongolian cherry (courtesy of USDA Soil Conservation Service Plant Materials Center, Bismark, ND).*

collection. Delayed harvesting of fruit improved germination and later ripening varieties had higher germination rates. This was attributed to incomplete embryo development within the seed (1). A warm stratification period should allow embryo development to take place.

We evaluated stratification treatments for overcoming dormancy in the seed of *P. fruticosa* and *P. maackii.*

Figure 2—*Foliage and fruit of 'Scarlet' Mongolian cherry (courtesy of USDA Soil Conservation Service Plant Materials Center, Bismark, ND).*

Materials and Methods

Fruit of *P. fruticosa* and *P. maackii* were collected when fully ripe in the summer of 1983. Pulp was removed by wet maceration and the seed were dried and then stored at 4 °C until removed for this study in January 1985.

Seeds of each species were then counted into lots of 100 for use in the stratification treatments. In a cutting test, 100 percent of *P. fruticosa* and 98 percent of *P. maackii* seed were sound.

Seed were stratified in damp peat moss in polyethylene bags for time lengths varying from 0 days warm + 60 days cold to 60 days warm + 120 days cold. Storage temperatures were 18 ± 2 °C for warm stratification and 4 °C for cold stratification. A total of 10 treatments plus a control treatment of 0 days warm + 0 days cold stratification were tested. Treatments of *P. fruticosa* were replicated three times; those of *P. maackii* twice.

At the end of each stratification period, seed were removed from storage and allowed to germinate at room temperature. Temperatures ranged from approximately 20 to 30 °C. Germination counts were made weekly and a total of 30 days was allowed for germination to take place.

Results

Prunus fruticosa and *P. maackii* seed responded with increased germination to combination treatments of warm and cold stratification as opposed to cold stratification only.

At 0 + 90 days stratification, 33 percent of *P. fruticosa* seed (table 1) germinated; at 0 + 150 days, 46 percent. With an addition of a 30-day warm treatment, the germination rate increased to 67.3 percent with 30 + 90 days. Longer cold stratification treatments resulted in germination and root elongation in storage, which would make mechanical seeding difficult. Substitution of a 60-day warm treatment for the 30-day warm treatment did not increase germination percentage and resulted in in-

Table 1—*Germination of* Prunus fruticosa *following stratification treatments and 30-day germination period*

Treatment	Germination per 100-seed lot	Total germinants in 3 lots	Percent germination
Control			
0 + 0	0	1	0.003
	0		
	1		
0 + 60	11	31	10.3
	8		
	12		
0 + 90	26	99	33.0
	31		
	42		
0 + 120	36	107	35.6
	35	Germination in storage	
	36		
0 + 150	39	138	46.0
	46	Excessive germination and root elongation in storage	
	53		
30 + 60	41	107	35.6
	29		
	37		
30 + 90	62	202	67.3
	74	Beginning radicle emergence; check at 75 days cold for germination	
	66		
30 + 120	68	207	69.0
	70	Excessive germination and root elongation in storage	
	69		
60 + 60	56	181	60.3
	64	Germination in storage	
	61		
60 + 90	66	201	67.0
	68	Excessive germination and root elongation in storage	
	67		
60 + 120	63	195	65.0
	69	Excessive germination and root elongation in storage	
	63		

creased germination in storage.

Seed of *P. maackii* (table 2) showed a positive response to warm stratification followed by cold stratification. Germination rate after cold stratification ranged from 0 to 4 percent but increased to a high of 64 percent with a treatment of 30 + 60 days. As with *P. fruticosa*, the use of longer cold stratification or of longer warm stratification periods resulted in increased germination in storage.

Both species contained cracked endocarps on many of the seeds after the warm stratification periods. Germination, however, did not occur without the cold treatment.

Discussion

These results indicate that 30 days of warm stratification followed by 90 days of cold will increase germination of *P. fruticosa* when stratified seed are required for spring nursery planting. It is recommended that checks on the seed in storage begin at 75 days of cold to insure that excessive root elongation does not take place. If germination does begin, the storage temperature can be lowered to just above 0 °C to slow root elongation.

Prunus maackii requires a 30 day warm stratification period preceding the 60-day cold stratification for germination to occur. Cold

Table 2—*Germination of* Prunus maackii *following stratification treatments and 30-day germination period*

Treatment	Germination per 100-seed lot	Total germinants in 2 lots	Percent germination
Control			
0 + 0	1 1 2 0	1	0.005
0 + 60	1 3 2 5	8	4.0
0 + 90	1 1 2 2	3	1.5
0 + 120	1 0 2 0	0	0.0
0 + 150	1 2 2 1	3	1.5
30 + 60	1 60 2 68	128 Radicle emergence & some root elongation	64.0
30 + 90	1 61 2 53	114 Germinating in storage	57.0
30 + 120	1 54 2 52	106 Excessive germination & root elongation in storage	53.0
60 + 60	1 51 2 56	107 Germinating in storage	53.5
60 + 90	1 46 2 56	102 Germinating in storage	51.0
60 + 120	1 57 2 52	109 Excessive germination & root elongation in storage	54.5

stratification only resulted in unacceptable germination percentages.

A practical nursery approach would be early fall seeding of *P. fruticosa* and *P. maackii* when at least 30 days still expected. Beds should be mulched and kept evenly moist until winter freeze up occurs. Germination will then take place the following spring.

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