Tree Planter's Notes, Vol. 37, No. 1 (1986)

Relationship of Filled Seed Set and Pounds of Cleaned Seed Yield per Bushel of Ponderosa Pine *(Pines ponderosa* Dougl. ex. Laws.) Cones in the Southwest

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*A cone and seed study of ponderosa pine (*Pines ponderosa *Dougl. ex Laws. and* P. ponderosa *var.* scopulorum*) showed good correlations between filled seed set counts, filled seeds per cone, and pounds of seed yield per bushel of cones. In this study, the term filled seed set refers to half the number of gametophyte-filled cut seeds exposed on both faces of a cone that has been cut along its longitudinal axis.* (Tree Planters' Notes 37(1):3-4; 1986)

An average of 12,360 acres have been planted each year on national forest lands in Arizona and New Mexico from 1980 through 1984. Almost 86 percent of these acres were planted with ponderosa pine. It is therefore important to provide the best available information to cone collection planners for estimating seed yields of cone crops for this species. The most useful information is expressed in pounds of clean seed yield per bushel of cones. Such information has been limited to a range and/or average of data reported in USDA Agriculture Handbook No. 450 (2). No previous work has been done to correlate an average filled seed-set count to clean seed yield per bushel of cones collected from this species. Olson and Silen (1) made a correlation of Douglas-fir filled seeds per cone to filled seed sets and provided data to estimate clean seed yield per bushel of cones.

Methods

Closed cones from the 1983 fall collections were cut lengthwise to expose cut seeds on each face (fig. 1). Filled cut seeds were counted on both faces and divided by 2 to determine an average seed-set count for one face. Both halves of each cone were put into a paper lunch sack. Each sack was labeled with the associated filled seed-set count. After the cones dried and opened in the sacks, seeds were extracted by peeling each scale from the fertile part of the cone axis. Dewinging was done by hand rubbing. Filled cut seeds were discarded as prerecorded data. Unfilled cut seeds were recorded. Uncut seeds were placed on a solid foundation and cracked with a small hammer. Cracked seeds were examined and recorded as filled or unfilled.

Cone lot shipments were checked at the Albuquerque Tree Nursery to verify that the number of bushels shipped agreed with Forest Service records. Twenty closed cones from each lot were cut, and filled seed sets were counted, averaged, and recorded. Normal cone drying, seed extraction, and cleaning procedures were then followed. After seed lots were dried for storage, they were weighed, counted, and recorded.

A linear regression analysis was done first to determine the relationship of filled seed-set counts to filled seeds per cone. This information was used in the following formula to estimate the number of cones in a bushel:

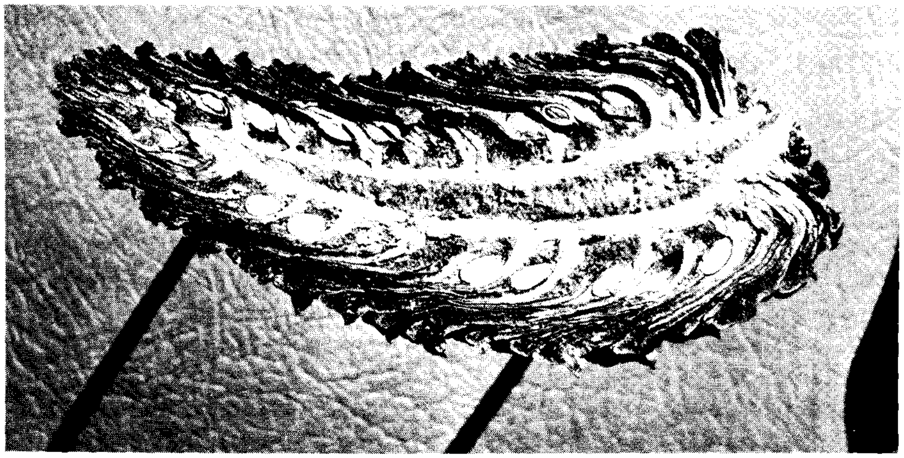

Figure 1—*Cut face of a ponderosa pine cone that had an average of 10 cut-filled seeds exposed on both faces, for a filled seed-set count of 10.*

$$C = 1/Y \times V \times N$$

where:

C = cones per bushel,

$1/Y$ = the reciprocal of filled seeds per cone for an average filled seed-set value entered on the calculated linear regression line,

V = pounds of clean seed extracted per bushel of cones, and

N = number of clean seeds per pound.

If any estimate was less than 100 cones, or exceeded a calculated average of 255 cones per bushel by 100 cones, the nursery data were presumed to be seriously flawed by a filled seed-set sample error. An error of this nature would occur if by chance the sample was not a true representation of the cone lot. "Flawed" data were not used to calculate the linear regression line for pounds of cleaned seed yield per bushel of cones.

Results

Raw data from this study may be obtained by writing to the author of this paper. Filled seed-set counts and filled seeds per cone are strongly related (r = 0.88) (fig. 2). The relationship between filled seed-set counts to pounds of clean seed yield per bushel of cones is weaker (r = 0.63).

Of the 68 southwestern ponderosa pine seed lots processed at the nursery, only 8 were considered to be seriously flawed by filled seed-set sample errors. These lots showed an estimated low of 98 cones per bushel and a high of 524 cones per bushel. Eliminating these data improved the correlation by 44 percent.

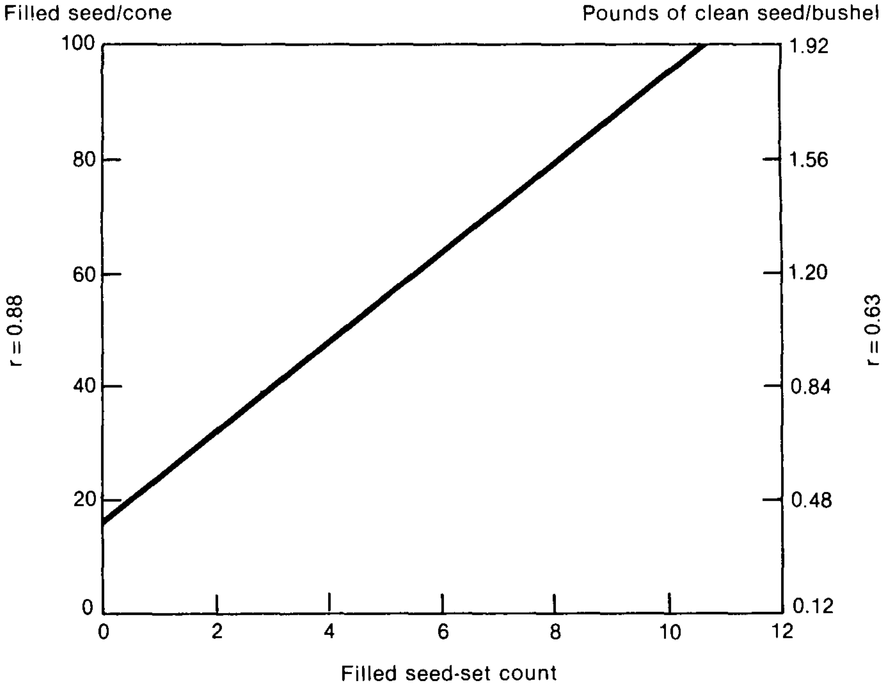

Figure 2—*Relationship of filled seed-set counts to filled seeds per cone (Y = 16.987 + 7.668X) and pounds of clean seed per bushel (Y = 0.433 + 0.137X) ponderosa pine.*

Conclusions

Although the relationship between filled seed sets and pounds of clean seed yield per bushel of cones is weaker than expected, it is reliable for use and more valid than using a range or average of data from geographically different sources. Obtaining filled seed-set counts from on-going cone collection activities and applying the average to the results of this study would detect local yield variations. Cone collectors could then adjust operations accordingly.

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Nursery Application of Benomyl Fungicide for Field Control of Brown-Spot Needle Blight (Scirrhia acicola (Dearn.) Sigg.) on Longleaf Pine (Pinus palustrus Mill.)

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*A benomyl fungicide treatment of longleaf pine (*Pinus palustris *Mill.) seedlings generally improves field survival and significantly controls brown-spot needle blight infection.* (Tree Planters' Notes 37(1):5; 1986)

A benomyl (Benlate®) fungicide treatment of the roots of longleaf pine (*Pinus palustrus* Mill.) seedlings at the nursery during the packing operation generally improves field survival and significantly controls brown-spot needle blight caused by the fungus *Scirrhia acicola* (Dearn.) Sigg. Forest pathologists of the Southern Forest Experiment Station and Forest Pest Management (region 8) in recent cooperative studies have found the benomyl treatment to be extremely effective in every test completed to date.

Benomyl has been recently registered by the EPA as a root-dip treatment for the control of brown-spot needle blight on longleaf pine prior to packing at the nursery or at the forestation site (Supplemental Labeling EPA Reg. No. 352-354). Under this new labeling, seedling roots are prepared by dipping them in clean water and allowing excess water to drain off. Seedling roots are then covered with a benomyl-kaolinite clay mixture [1 ounce of benomyl (WP-50) and 9.5 ounces of dry kaolinite] by shaking roots for 15 to 20 seconds in a suitable container, such as a plastic bag, containing the clay mixture. This represents a dosage rate of 5 percent (wt/wt) active ingredient.

Based on these guidelines, nurseries can now treat a large number of longleaf pine seedlings with benomyl prior to packing and storing for shipment to their customers. Benomyl can also be applied by those nurseries that use a kaolinite clay mixture as the packing material for seedling storage. The benomyl-kaolinite solution in this case is made in a mixing tank by combining 50 pounds of the clay and 5.25 pounds of benomyl with enough water to obtain a solution that will adhere to the root systems of the seedlings. This benomyl-clay mixture should be sprayed on the seedlings' roots as they are packed in the shipping bags. Each nursery can modify these amounts to the capacity of its mixing tank, while maintaining the ratio of benomyl (WP-50) to kaolinite clay at 1 to 9.5, by weight.

When using the solution, several precautions should be noted: (1) Before using benomyl, read and carefully observe the cautionary statements and all other information appearing on the product label; (2) avoid applying the mixture to seedling foliage; (3) avoid exposing the roots to abnormally high temperatures (that is, above 90 °F), freezing temperatures, or to excessive drying conditions; and (4) use special care to avoid loss of the mixture from the treated roots during seedling packing, storage, transport, and field planting.

A paper summarizing all the experimental results of benomyl-clay treatment in the nursery will be published in a forthcoming issue of Tree Planters' Notes. Further information on the supplemental labeling is given in the agricultural bulletin issued by E. I. Du Pont De Nemours & Co. dated November 16, 1984, and entitled, Supplemental Labeling, EPA Reg. 352354, Benlate® Fungicide for Control of Brown-spot Needle Blight on Longleaf Pine. Specifics of using benomyl on longleaf pine can be obtained from A. G. Kais, Southern Forest Experiment Station, P.O. Box 2008, GMF, Gulfport, MS 39505, phone (601) 864-8256; or C. E. Cordell, Forest Pest Management, P.O. Box 5895, Asheville, NC 28803, phone (704) 259-0643.

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Tillage Superior to No-till for Establishing Hybrid Poplar Plantations'

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In this study on the effects of till and no-till on early survival and growth of hybrid poplar, till was always superior to no-till regardless of site, clone, or planting material. Over the three sites, tillage produced the greatest tree growth on the loam soil, the wettest and most fertile of the sites. In contrast, no-till showed its best performance on the dryer (and therefore probably warmer) sandy loam site. (Tree Planters' Notes 37(1):6-10; 1986)

Hybrid poplar (*Populus* spp.) plantations are typically established on old field sites that are heavily infested with weeds. For successful establishment of poplars, these weeds must be controlled. Site preparation and weed control are most commonly accomplished by a combination of herbicides and tillage (3,6). However, mechanical tillage is energy-expensive (8). No-till site preparation methods using herbicides alone are alternatives for possible reductions in site preparation costs. Also, no-till has the advantage of improving trafficability on wet sites. However, two plantation establishment studies using unrooted hybrid poplar cuttings as planting material have shown no-till to be inferior to tillage on imperfectly drained clay loam soils in Ontario (9) and on silt loam soils in Wisconsin (4). Both of these studies compared a range of site preparation intensities and in both cases no-till was the poorest in terms of tree growth. The no-till treatment in Ontario also resulted in poorer tree survival.

During the period these studies were in progress, the point was frequently discussed that 1 +0 rooted hybrid poplar stock may grow as well under a no-till system as under a till system or better. No-till with 1 +0 rooted stock is the system used by Packaging Corporation of America (PCA) for planting several thousand hectares in northern Lower Michigan. Because of the potential economic savings and increased versatility of no-till, a broader data base for comparing no-till with the more common tillage systems would be useful. So a study was begun in 1981 on PCA land near Manistee, MI, to compare the effects of till with those of no-till on early survival and growth of hybrid poplar. The study included two clones and two types of planting stock, and was installed on three different sites to check the consistency of results across soil types.

Methods

The experimental design was a split-split plot with 2 replications. Clones were the main plots, tillages the subplots, and planting stock the sub-subplots. Trees were machine planted at a 2.4- by 3.0meter spacing with 2 rows in each sub-subplot. Rows were a minimum of 50 meters long.

The soil types consisted of a poorly drained Bergland loam developed under mixed lowland hardwoods and swamp conifers (loam). The area had been previously used as pasture and wild carrot (*Daucus carota* L.) predominated. A fine-clay subsoil contributed to poor drainage and formed an impermeable barrier to rooting 48 to 50 centimeters below the soil surface. (The water table was at 0.50 meter on October 28, 1981.) A second site was a well-drained Emmet sandy loam formed under sugar maple, beech, and hemlock (sandy loam). There were no impediments to rooting (plow pans or fine-textured layers), and the soil structure was fine granular. (The water table was at 1.7 meters on November 3, 1981 .) Emmet is considered one of the best soils in the area for fruit, potatoes, and alfalfa. The site had been in pasture for several years and plant cover consisted of crownvetch (*Coronilla varia* L.) and alfalfa (Medicago sativa L.) The third site was an excessively drained Kalkaska sand that had not been farmed for at least 3 years before this study (sand). Moisture-holding capacity of this soil is poor because of its coarse texture and loose consistency throughout the deep soil profile. Sludge was applied 10 to 15 centimeters below the surface in 1978 on this latter site. Although sludge application may have raised the

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surface soil pH, it did not affect moisture-holding capacity and soil fertility.

All three sites were sprayed with glyphosate (Roundup) at 2.2 kilograms of active ingredient per hectare on October 26, and the tilled areas were plowed November 6, 1981 and disked May 15, 1982. All areas were machine planted on May 25-26, 1982. Linuron was applied over the cuttings after planting at 2.2 kilograms of active ingredient per hectare. No further treatments were applied thereafter.

Hybrid poplar clones used for the study were NE-19 *Populus nigra charkowiensis x P. nigra caudina and* DN-34 (*P. x euramericana* 'Eugenei'). Planting stock produced by the PCA nursery consisted of 1year-old (1 +0) bareroot stock grown from cuttings and unsoaked unrooted hardwood cuttings. Half of the hardwood cuttings were soaked, but only for 1 or 2 days; there was no noticeable soaking response and all hardwood cuttings were therefore considered as "unsoaked" in the analysis.

Tree survival and height growth were sampled by establishing a straight-line transect across the entire plot perpendicular to the treatments. Within each row, the 3 closest living trees on each side of the transect were measured. Dead trees within the group of 6 living trees were also recorded. The data were collected each fall for the 3 years following planting and were analyzed by standard ANOVA techniques. Significance was evaluated at P = 0.05.

Results

Mortality. Most of the mortality occurred after the first year. By the end of the third year there were significant differences in mortality within tillage treatments, planting stock types, and clones (table 1). Although mortality was 15 percent in the no-till areas and 4 percent in the tilled areas, most of the mortality in the no-till areas was associated with the unrooted planting stock. Unrooted cuttings had significantly higher mortality than rooted stock in the no-till areas (24 versus 4 percent) but only slightly higher mortality in the tilled areas (7 versus 2 percent-not significant).

Growth. Effect of tillage, planting stock, and clone on tree height was similar each year. Consequently, only the third year's data are presented.

Trees were significantly taller on tilled areas than on no-tilled areas for both clones on all three sites (table 2). Tree height averaged 2.70 meters on tilled areas and 1.86 meters on the no-till, a 45 percent difference.

There was a significant interaction of tillage with site. Tillage produced the tallest trees on the loam site. However, the best site for no-till was the sandy loam (although tillage still produced taller trees on that site).

There was also a consistent significant advantage of till over no-till regardless of the type of planting material (table 3). Unrooted cuttings were 0.78 meter (46 percent) taller with tillage than with no-till; rooted stock was 0.90 meter (50 percent) taller. Rooted stock averaged 0.45 meter tall when planted; cutting height was negligible when planted. However, DN-34 unrooted cuttings grew faster than rooted stock, so that at the end of 3 years the rooted stock was only 0.10 meter taller than the unrooted cuttings. In contrast, NE-19

Table 1—*Effect of tillage, planting stock, and clone on mortality during the first 3 years*[1]

Treatment	Mortality (percent)
Tillage	
Till	4a
No-till	15b
Planting stock	
Rooted stock	3a
Unrooted cuttings	16b
Clone	
NE-19	6a
DN-34	13b

[1] Treatments followed by different letters are significantly different from each other.

Table 2—*Effect of clone, tillage, and site on 3-year-old hybrid poplar height (m)*

	DN-34		NE-19		
Site	Till	No-till	Till	No-till	Average
Loam	2.73	1.63	4.28	2.18	2.70
Sandy loam	2.39	1.83	3.07	2.41	2.42
Sand	1.68	1.38	2.01	1.70	1.69
Average	2.27	1.61	3.12	2.10	
	1.94		2.61		

Table 3—*Effect of clone, tillage, and planting material on 3-year-old total tree height and actual shoot growth of rooted stock (m)*

	DN-34		NE-19	
Plant material	Till	No-till	Till	No-till
Unrooted cuttings	2.19	1.60	2.80	1.82
Rooted 1 + 0	2.35	1.63	3.43	2.36
Rooted (growth)	1.89	1.12	3.03	1.93

cuttings grew somewhat slower than rooted stock, so that at the end of 3 years the rooted stock was 0.58 meter taller than the cuttings.

There were significant differences in tree height between sites-trees on the loam site averaged 0.28 meter taller than those on the sandy loam, and 1.01 meters taller than the ones on the sand (table 4). There were also significant differences between tillage treatments, clones, and planting stock types. The best tillage practice, clone, and planting stock each individually contributed 0.84, 0.67, and 0.34 meter, respectively, to tree height. Combining the best tillage practice and clone resulted in a 1.51-meter (94 percent) height advantage over the poorest combination. And combining the best tillage practice, clone, and site resulted in a 2.90-meter or 310 percent height advantage over the poorest combination of those three variables.

A final interesting comparison is that of no-till with rooted stock versus tillage with unrooted cuttings (the major systems used by PCA and the USDA Forest Service at Rhinelander, WI, respectively) (table 4). There was only a 0.03-meter (3 percent) height advantage for the tillage and cutting system at the end of the first growing season. But by the end of 3 years, the tillage and cutting system averaged 0.50 meter (25 percent) taller than the no-till and rooted stock system.

Discussion

The poor performance of the no-till treatment in this test confirms results of earlier till and no-till site preparation trials made on an imperfectly drained clay loam soil (9) and on a well-drained silt loam soil (4). No-till and other practices that leave plant residues on the soil surface result in higher soil moisture in the plant root zone and lower spring soil temperatures (1). The moisture-retaining characteristic of no-till is an advantage on droughty soils but is a disadvantage on poorly drained soils. Agricultural studies show that tillage practices (including no-till) that leave residues on the soil surface are better adapted to the longer, warmer growing seasons in the southern half of the Corn Belt and farther south (5). The fact that no-till results were best on the sandy loam, in contrast to tillage doing best on loam, suggests that the more rapidly warming sandy soils might be partially compensating for the insulating effect of no-till; and that soil temperature is indeed a negative feature of no-till.

Another potential benefit of no-till might be the improved trafficability, particularly for early spring planting. It has been argued that the earliest possible spring planting date for hybrid poplar is best. If so, no-till with its associated better trafficability could be beneficial. However, it has been shown that later planting (when soils are warmer) results in the greatest tree growth for at least the first 2 years

Table 4—*Comparison of 3-year-old hybrid poplar tree heights showing effects of several factors, singly and in various combinations**

Treatment/condition	Tree height (m)	Difference (m)	Percent difference
Site			
1. Loam	2.70a	0.28	12
Sandy Loam	2.42b		
2. Loam	2.70a	1.01	60
Sand	1.69c		
Tillage			
Till	2.70a	0.84	45
No-till	1.86b		
Clone			
NE-19	2.61a	0.67	35
DN-34	1.94b		
Planting material			
Rooted	2.44a†	0.34	16
Cuttings	2.10b		
Tillage + clone			
Till + NE-19	3.12a	1.51	94
No-till + DN-34	1.61b		
Tillage + clone + site			
Till + NE-19 + loam	4.28a	2.90	310
No-till + DN-34 + sand	1.38b		
Tillage + planting material			
Till + cuttings	2.50	0.50	25
No-till + rooted	2.00		

*Values in a treatment class followed by different letters differ significantly.

†Data shown are total height; growth was 1.99 m.

(2). In fact, because a no-till system retards soil warming, it would tend to further delay the optimum planting date. However, even though no-till and early planting result in reduced growth, early planting with no-till may still be necessary with a large operational planting program that spans many weeks. For short-duration planting programs, early planting and no-till should probably be avoided.

The type of planting stock had no effect on which site preparation method was best; tillage was always superior to no-till. However, the best type of planting material could vary with clone. Although rooted stock was the tallest at the end of 3 years for both clones, it was only marginally taller for clone DN-34. Soaking the cuttings of clone DN-34 before planting could easily cause the unrooted cuttings to surpass the rooted stock (7).

Conclusions

Based on the consistently poorer results of no-till in this and other cited tests, we conclude that no-till will probably not be as suitable as other site preparation methods involving tillage at these northerly latitudes. Also, matching the best tillage practice and clone with the proper site can produce tree height several times that attained with the poorer combinations.

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Black Walnut *(Juglans nigra* L.) Establishment: Six-Year Survival and Growth of Containerizec and 1 + 0 Seedlings

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*Outplant survival and growth of containerized black walnut (*Juglans nigra *L.) was compared with that of bareroot 1 +0 seedlings. Survival of containerized seedlings was significantly lower than that of 1 +0 seedlings but the avoidance of outplanting shock produced a significant growth advantage for the surviving containerized seedlings.* (Tree Planters' Notes 37(1):1 1-14; 1986)

Black walnut (*Juglans nigra* L.) has traditionally been planted as 1 +0 bareroot seedlings. However, walnut seedlings are subject to outplanting shock, which limits growth during the first year following outplanting. To determine if planting shock could be avoided and early growth increased by planting containerized seedlings, field performance of black walnut in tarpaper containers was compared with that of bareroot seedlings from the same seed source. This report presents the 6-year results.

Methods

In the autumn of 1978, black walnut seeds from selected sources in Indiana and Michigan were hulled and stratified in moist sand at 0.5 °C. In April 1979, half of the nuts were sown in a nursery and the other half were germinated in a greenhouse and sown into tarpaper containers, one nut per container. The open-ended containers, made of 19 types of commercially available tarpapers ranging in wall thickness from approximately 0.05 to 0.09 millimeter, measured 6.5 by 6.5 by 20 centimeters (fig. 1). Six of the tarpapers were formed into containers that were 6.5 by 6.5 by 30 centimeters. The growing medium was 75 percent peat and 25 percent loam without amendments.

Figure 1—*Containerized seedling at time of outplanting.*

The seedlings were grown in a greenhouse under extended photoperiods of 16 hours and a temperature of approximately 18 °C (night) and 28 °C (day). After 6 weeks the seedlings were transferred to shade frames for 2 weeks of conditioning. In the middle of June the container stock was planted by spade into well-drained loam in a fully cultivated field near Parkhill in southern Ontario. At the time of outplanting the seedlings were 20 centimeters high and actively growing (fig. 1).

In April of the following year, rows of bareroot seedling stock grown in the nursery were planted by spade between rows of containerized seedlings from the same seed sources. Of all the seedlings planted, 204 were in containers 20 centimeters high, 32 were in containers 30 centimeters high, and 271 were 1 +0 nursery-grown stock.

The entire plantation was kept weed-free by annual applications of simazine (5.0 kilograms/hectare) and spot treatments of glyphosate (2.0 kilograms/hectare). The roots of each of three trees planted in containers and of three trees planted as 1 +0 seedlings were excavated in the autumn of 1984, photographed, and examined for possible differences in root development. Survival and height were recorded each autumn for the first 6 years after planting, and the sixth-year survival and height data were analyzed by the Chi-square test and analysis of variance, respectively.

Results

There were no significant differences in either survival or growth of trees grown in tarpaper containers of varying thicknesses or lengths. Therefore, data from the various container treatments were combined. Six-year survival of trees planted in containers and as 1 +0 nursery-grown seedlings was 87 and 94 percent, respectively, with a significant difference at

P<0.05. However, nearly all mortality of the containerized seedlings occurred in the year of planting and was probably related to lack of hardening off.

At the end of the sixth growing season, total heights of containerized and bareroot seedlings were 416 and 385 centimeters, respectively (table 1). The difference was statistically significant (P = 0.05) and was mainly the result of outplanting shock suffered by the 1 +0 seedlings (fig. 2). There were no discernible differences in root development of the containerized and nursery-grown seedlings (fig. 3 and 4).

Table 1—*Height growth of containerized and bareroot seedlings by years from seeding*

Years from seeding	Containerized seedlings (cm)	Bareroot seedlings (cm)
1	27	33
2	54	19
3	88	70
4	67	78
5	33	44
6	147	141
Total height	416	385

Discussion

The biological advantages of containerization are well known, and black walnut seedlings have been grown in a variety of containers with different potting media, soil amendments, length of photoperiods, and other treatments to accelerate growth (1-7). Most experiments have shown that early

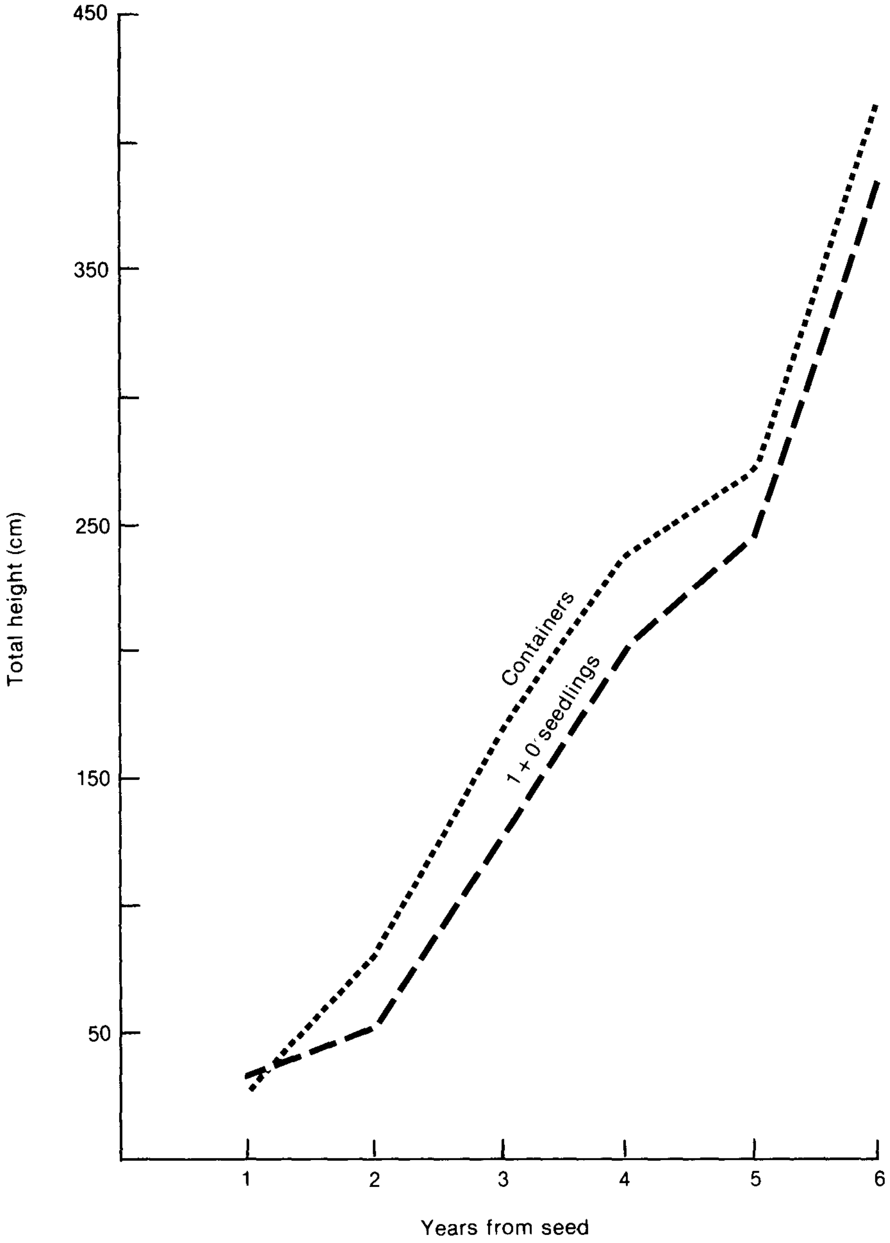

Figure 2—*Height of black walnut seedlings planted either in containers or as 1 + 0 nursery-grown seedlings.*

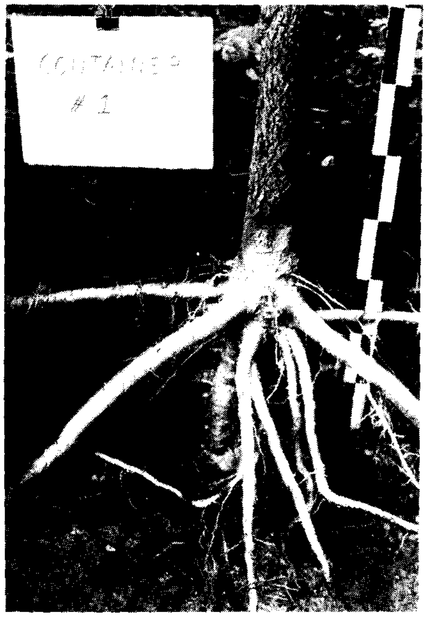

Figure 3—*Root form of containerized seedling.*

growth can be increased by containerization, but little information is available on the field performance and extended growth of these seedlings in comparison with those of bareroot seedlings.

Black walnut seedlings require large containers to accommodate the nut, the pronounced tap root, and the large fibrous root system that develops before the fragile shoot is sufficiently hardened off to withstand injury during transport and outplanting. Wet tarpaper presented no barrier to root penetration (fig. 5). However, all root egress during the greenhouse phase was restricted to the lower half of the tarpaper cubes, which were kept wet by contact with the other cubes in the holding trays. Figure 6 shows that the roots near the soil surface have grown downward along the side of the container wall, either because they were unable to penetrate the dry tarpaper or because the root tips were air pruned.

Conclusions

Planting black walnut seedlings in containers can be a means of avoiding outplanting shock, and growth can thereby be increased during the early years after outplanting. However, the high cost of

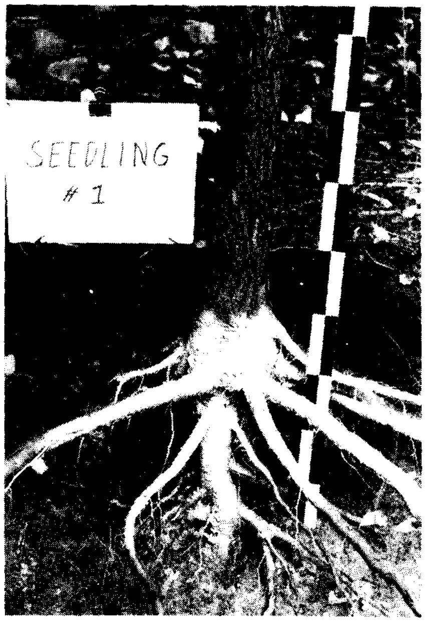

Figure 4—*Root form of nursery-grown seedling.*

Figure 5—*Root egress through tarpaper wal at time of outplanting.*

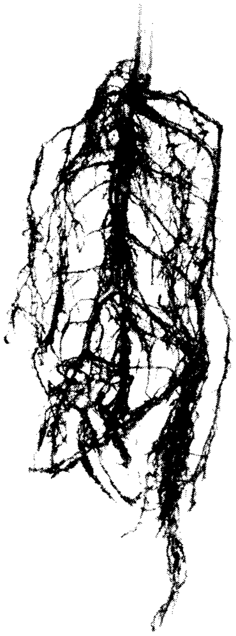

Figure 6—*Root system of containerized walnut seedling at time of outplanting, exposed by removal of container and washed to show root system form.*

production, transportation, and outplanting will probably restrict containerization to growing high-value seed or for use in reforestation when rapid early height growth is important to the success of the plantation.

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Tree Planter's Notes, Vol. 37, No. 1 (1986)

Effects of Root-Coating With the Polymer Waterlock on Survival and Growth of Drought-Stressed Bareroot Seedlings of White Spruce (*Picea glauca* (Moench) Voss) and Red Pine (*Pines resinosa* Ait.)

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*Root coating with a superabsorbent polymer is a recommendable precautionary measure against drought-induced mortality in areas with frequent dry spells during the planting season. Root-coated white spruce (*Picea glauca *(Moench) Voss) exposed to no more then 2 weeks of post-planting drought showed a significant improvement of 24 percent in survival as compared to untreated seedlings. Root coating had not significant effect beyond 2 weeks of drought.* (Tree Planters' Notes 37(1):15-19; 1985)

Plantations established with bareroot seedlings in areas of periodic summer droughts are susceptible to increased drought-induced mortality rates (1, 3, 5, 8, 16).

Improvements in survival rates and growth of newly transplanted bareroot seedlings can be achieved by modifying the plant water balance. This is done either by reducing water losses through transpiration *(4,* 5, *20, 22)* or by facilitating water uptake *(14).* The latter is accomplished when the root system is provided with a sufficient and easily tapped water supply until the plant becomes self-sustaining.

Dipping the roots of bareroot seedlings into a water-based gelatinous solution of a hygroscopic substance is a simple and inexpensive technique to provide plants with accessible water for the first critical weeks after planting *(2, 14).* In this paper, the effect of such a treatment on survival and growth of white spruce (*Picea glauca* (Moench) Voss) and red pine (*Pines resinosa* Ait.) bareroot seedlings are examined. Both species are widely used in reforestation programs throughout the Great Lakes region *(3, 24),* where recurrent warm and dry spells take their toll on newly established plantations. Although root-dipping with wetting substances has been known for many years in forestry (6), few critical studies have been made of the value of this treatment (7). The emergence of new superabsorbent polymers with improved absorption and retention capabilities calls for renewed evaluations.

Materials and Methods

A complete randomized block trial was established in May of 1984 on a sandy field at the Orono Forest Station, Ontario Ministry of Natural Resources (lat. 43°58' N., long. 78°37' W.). Treatment combinations (species x root coating x drought level) were replicated 3 times with six plants per replicate. .

The bareroot seedlings of white spruce (2 + 1) and red pine (2 + 0) were both of regional origin. The red pines were lifted in the third week of April 1984 and kept bagged in cool storage until May 9. The white spruce seedlings had been in cold storage since the end of October of 1983. Seedlings were planted manually on May 9 and were spaced at 0.3 x 0.3 meters within each plot. Initial plant sizes are listed in table 1.

Half the plants were treated immediately before planting by submerging their root system into a prepared gelatinous solution of Waterlock and water (1:160, w/w) Waterlock is a hydrolized starch polyacrylonitrile graft polymer potassium salt (Grain Processing Corp., Muscatine, IA). An average of approximately 100 grams of the gelatinous coating medium adhered to each treated plant.

Table 1—*Initial size of bareroot seedlings*[1]

	Age	Length (cm)	CV (%)	Diameter[2] (mm)	CV (%)
White spruce	2+1	27.3	19.1	6.2	22.5
Red pine	2+0	23.5	23.2	5.0	18.2

[1] CV = coefficient of variation.
[2] Measured 1 cm above the uppermost lateral root.

The drought treatments consisted of shielding the plants from natural precipitation for six different lengths of time following planting. To this end, lattice frames covered with transparent plastic foil were erected 1 meter above each plot. The slightly tilted (E-W) lattice roofs permitted passage of 50 percent of incoming radiation and had

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[1] The provision of plant material, site facilities, and technical support by the Orono Forest Station (Ontario Ministry of Natural Resources) and the help of its superintendent, G. R. McLeod, are gratefully acknowledged. The Grain Processing Corp., Muscatine, IA, generously donated the polymer Waterlock used in this study.

a 30-centimeter overhang on all plot borders. Encompassing each plot, a 50-centimeter-deep ditch lined with plastic collected runoff water and prevented root outgrowth from the plots. The rain shelters were removed 1, 8, 13, 19, 27, and 34 days after planting. Bud flushing and terminal leader growth were assessed weekly on all plots during the period from May 17 to July 3.

Xylem pressure potential measurements were taken on individual fascicles for red pine and on lateral branch tips for white spruce by use of a pressure chamber and handheld lens. Precautions were observed following recommendations of Ritchie and Hinckley (19). On selected days, midday xylem pressure potentials were taken on seedlings of each sample population from three additional plots established for this purpose.

All live plants were harvested on October 3, 1984, and their heights and root collar diameters recorded. Root and shoot dry matter contents were determined later. Plant dry matter was obtained after 48 hours drying at 80 °C in forced-air ovens. The significance of treatment effects (that is, root coating and drought) on dry-matter content, height, and shoot to root ratios was assessed separately for each species by means of two-way analyses of variance with frequency weighted means and interactions. Survival rates were compared on a logit-scale (3). Statistical comparison of bud release and height growth was done by means of an ordinary two-sample t-test for grouped data (3).

Results and Discussion

In treatments with less than 19 days of shielding from natural precipitation, root-coating significantly (P = 0.05) improved survival in white spruce seedlings by an average of 24 percent. Longer post-planting drought treatments reduced the positive effect of root-coating in white spruce to a non-significant level (table 2). The survival rates in red pine were exceptionally good regardless of treatment and were so nearly identical as to preclude any influence

Table 2—*Survival, height growth, dry matter, and shoot to root ratios of root-coated (R) and control (C) white spruce and red pine seedlings after 1 to 34 days of drought treatment (shielding from natural precipitation) after planting (May 9)*[1]

	1 day	8 days	13 days	19 days	27 days	34 days	Average
Rainfall received[2] (mm)	207	191	191	173	160	160	—
White spruce							
Survival (%)							
R	72ab*	78a*	83a*	67bc	61c	33d	66
C	60a	50b	50b	56ab	50b	39c	51
Height growth (cm)							
R	10.0a	8.3ab	7.3bc	6.7bc	5.0c	4.6	7.0
C	8.5a	8.1ab	6.8ab	7.3ab	5.4b	5.5	7.3
Dry weight (g)							
R	35.1	30.2	26.4	29.3	21.6	24.0	28.8
C	35.9	33.0	30.9	28.4	27.3	26.6	30.7
Shoot/root growth							
R	2.4	2.4	2.3	2.4	2.9	2.7	2.6
C	2.6	2.6	2.8	2.9	2.7	3.2	2.8
Red pine							
Survival (%)							
R	100a	100a	94a	94a	83b	89ab	94
C	94a	100a	94a	100a	83b	78b	92
Height growth (cm)							
R	11.5a	10.1abc	10.6ab	9.3abc	8.0bc	7.6c	9.5
C	12.9a	11.0ab	10.7ab	9.3ab	9.2b	8.4b	10.3
Dry weight (g)							
R	15.7a*	14.9a	12.5a	14.5a	10.1a	10.6a	13.0
C	20.3a	15.3b	13.2bc	10.6bc	12.1bc	9.3c	13.6
Shoot/root growth							
R	2.4b	2.6ab	3.1ab	2.9ab	3.3a	3.1ab	2.9
C	2.7b	3.0ab	3.1ab	3.1ab	3.7a	3.7a	3.2

[1] Treatment means (across rows) followed by a common letter do not differ at the 95% probability level, based on the "Studentized range" test (*23*).

[2] Rainfall received after removal of the rain shielding; data from the Orono Forest Station, May 9 through October 3.

*Significantly different from controls at the 95% probability level.

of root-coating (table 2). Neither species showed evidence of any simple relationship between survival and length of drought treatment. However, white spruce showed a distinct drop in survival in the longest drought treatment. The reason for the low survival rates in white spruce results from the low drought resistance of this species as compared to red pine (15, 17).

Height growth was significantly influenced by root-coating. In red pine, treated seedlings showed an average of 10 percent less growth than untreated seedlings (table 2). In white spruce, root-coating promoted height growth to a slight extent in those seedlings exposed to no more than 2 weeks of post-planting drought. Reverse effects were recorded in the longer lasting drought treatments (table 2). Root-coating did not significantly affect dry-matter content.

As expected, height growth and plant dry-matter content declined significantly with progressive duration of the post-planting drought treatment (9).

The ratio of shoot to root dry-matter content increased with the length of the drought period (table 2). This frequently observed reaction of drought stressed plants enhances the imbalance between water uptake and water loss through transpiration (11-13, 21, 23). Root-coating, on the other hand, lowered the ratio (table 2). The lowering of the shoot to root ratio has presumably contributed to the better survival of root-coated white spruce seedlings.

Plant water potential, measured at noon on three different days during May and June, showed no effect of root-coating. However, significant differences were found between species and between days (table 3). The higher values observed in the red pine seedlings reflect the better drought tolerance of this species (17). All water potential readings indicated a moderate to severe plant water stress common in transplanted seedlings at noon on warm, dry days (9, 10).

Table 3—*Midday plant water potential (MPa) of sheltered seedlings on 3 warm and dry days during the summer of 1984*[1]

	White spruce		Red pine		
Day	R	C	R	C	Mean
May 22	−1.72	−1.70	−1.15	−1.30	−1.47
June 5	−1.89	−1.81	−1.71	−1.53	−1.74
June 12	−2.14	−1.99	−1.49	−1.39	−1.75
Mean	−1.92	−1.83	−1.45	−1.41	−1.65

[1] R = root-coated seedlings, C = controls; standard error of difference = 0.1.

In white spruce, bud release and termination of height growth occurred 2 to 3 days sooner in the coated than in the untreated seedlings. Red pine, on the other hand, displayed no influence of root-coating on flushing or termination of growth. Table 4 lists flushing stages and percentages of total height growth on selected days in May, June, and July of 1984, The data are pooled across drought treatments due to the negligible impact of drought on bud release (18).

Summary

The effect of root-coating with the water-based, super absorbent starch polymer Waterlock on first-year survival and growth of transplanted bareroot seedlings of white spruce and red pine was assessed in a field experiment with six different periods of post-planting drought.

Root-coated white spruce exposed to no more than 2 weeks of post-planting drought showed a significant improvement of 24 percent in survival as compared to untreated seedlings. Over lengthy

Table 4—*Terminal bud release index (BRI) and percentage of total height growth (HG%) of surviving plants on different dates (May 7 to July 3) during the 1984 growing season*

Treatment[1]	May 17	May 22	May 28	June 5	June 12	June 19	June 26	July 3
White spruce								
BRI[2]								
R	0.8*	2.3*	3.8*	4.6*	5.0	—	—	—
C	0.4	1.8	3.3	4.2	5.0	—	—	—
HG%								
R	—	—	18.1*	47.9*	79.8*	85.3*	93.9	100.0
C	—	—	4.5	29.1	61.6	79.3	91.7	100.0
Red pine								
BRI[3]								
R	1.7	1.8	2.5	3.3	3.6	3.9	4.5	4.8
C	1.8	1.8	2.7	3.2	3.5	3.9	4.3	4.8
HG%								
R	—	—	—	29.4	66.5	71.6	79.7*	83.5
C	—	—	—	27.6	66.2	70.6	74.5	82.5

[1] R = root-coated seedlings, C = controls.

[2] 0 = dormant, 1 = swelling, 2 = translucent bud scales, 3 = emergence of first needles, 4 = brush-like opening, and 5 = shoot elongation.

[3] 0 = dormant, 1 = bud elongation, 2 = bud swelling and elongation, 3 = patchy wax deposits, 4 = emergence of short shoots, and 5 = shoot free to grow.

*Significantly different from controls at the 95% level.

periods of drought, root-coating no longer had a significant influence on the rate of survival. Survival in red pine was very high in both root-coated and untreated seedlings, with no significant effect of root-coating.

Root-coated seedlings of both species had lower shoot to root ratios than untreated seedlings, indicating comparatively better root growth.

Prolonging post-planting drought reduced growth significantly in all seedlings and increased the root to shoot ratio.

Readings of midday plant water potential showed the plants to be moderately to severely drought stressed, with no apparent effect due to root coating. Red pine had a significantly higher water potential than white spruce, indicating a better drought tolerance.

Bud release and termination of height growth occurred 2 to 3 days earlier in root-coated white spruce seedlings than in control seedlings. No such differentiation was observed in red pine.

It is concluded that root-coating with a superabsorbent polymer is a recommended precautionary measure against drought-induced mortality in areas with frequent dry spells in the planting season.

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Time of Germination: A Factor in Rate of Growth of Accelerated Transplants of Black Spruce (*Picea mariana* (Mill) B.S.P.)

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*Cotyledonous black spruce (*Picea mariana *(Mill) B.S.P.) seedlings, initiated in "cigarette" germination plugs, were planted in peat cubes over a range of dates in the greenhouse. Following midsummer transplanting, bareroot trees were sampled in the fall of each production year. Rate of growth through the first and second year in the nursery is related to time of germination. Second-year growth is related to size of stock after the first season in transplant beds. Rate of growth in terms of daily dry weight increment was found to be related to time of germination through both the first and second seasons in the nursery. Second-year growth was also related to stock size at the end of the first season.* (Tree Planters' Notes 37(1):20-24; 1986)

In a 2-year bareroot transplant system for black spruce (*Picea mariana* (Mill) B.S.P.), uniform early germination and rapid early growth are essential. The size of transplants after one and two seasons in nursery beds varied directly with the duration of growing period since the time of germination (6). The results were attributed primarily to an extended growing season.

An additional factor is the rapid growth achieved through the season by plants from early germinated seedlings. In an accelerated transplant system, that is, greenhouse-initiated seedlings for transplanting as eventual bareroot shipping stock, time and space are important considerations in both quality and cost of seedlings. Pre-germination of seed may save several days of greenhouse operations and ensure full initial stocking of uniformly developed plants.

This report relates rate of growth in terms of plant dry weight production and time of germination in a 2-year accelerated transplant system.

Methods and Materials

Mean plant data--root collar diameter, plant height, oven-dry weight of roots and shoots, and shoot to root ratio--have been published (6). Total plant dry-weight data are presented here in relation to the duration of growth during the two growing seasons.

Stratified seed was sown in "cigarette" plugs of commercial peat moss rolled with cellulose tea bag material for "paper" (6). Seed was germinated under optimum conditions recommended by Fraser (1). After they shed their seed coats, the cotyledonous seedlings were planted in peat cubes 2.5 centimeters square and grown in a greenhouse for 6 to 14 weeks (depending on date of germination), and then removed for 2 weeks of conditioning. Plants were transplanted in July of 1975 by hand in normal nursery beds at Orono Forest Station, Orono, ON (lat. 43°59' N. long. 78°37' W.).

Seed were germinated over a range of dates from February 15 to June 11. From 400 to 3,000 cotyledonous seedlings were planted at each sowing time and grown in trays of approximately 400 cubes each. Trees of each tray, identified by time of planting, formed separate plots in the nursery bed. The stock was treated according to standard nursery procedures through the remainder of 1975 and 1976.

Samples were lifted in the fall of each production year; about 20 bareroot transplants were taken in a line across each bed. For each assessment, measurements of height and root collar diameter were made on each tree. Roots were separated from tops at the root collar. Both were oven dried at 105 °C for 24 hours to determine the mean dry weights of plant samples.

Results

First-year growth in terms of total plant ovendry weight is represented by the slope of lines from date of sowing to weight of 1-year-old plants harvested in the fall of the first season in the nursery (fig. 1). Germinates from successive sowings exhibited lower rates of increase in plant dry weight.

In the second season, all plants experienced a full growing season from flushing in May to lifting of samples in November. Growth through the season exhibited similar relationships of increase in dry weight relative to germination date in the first year (fig. 2).

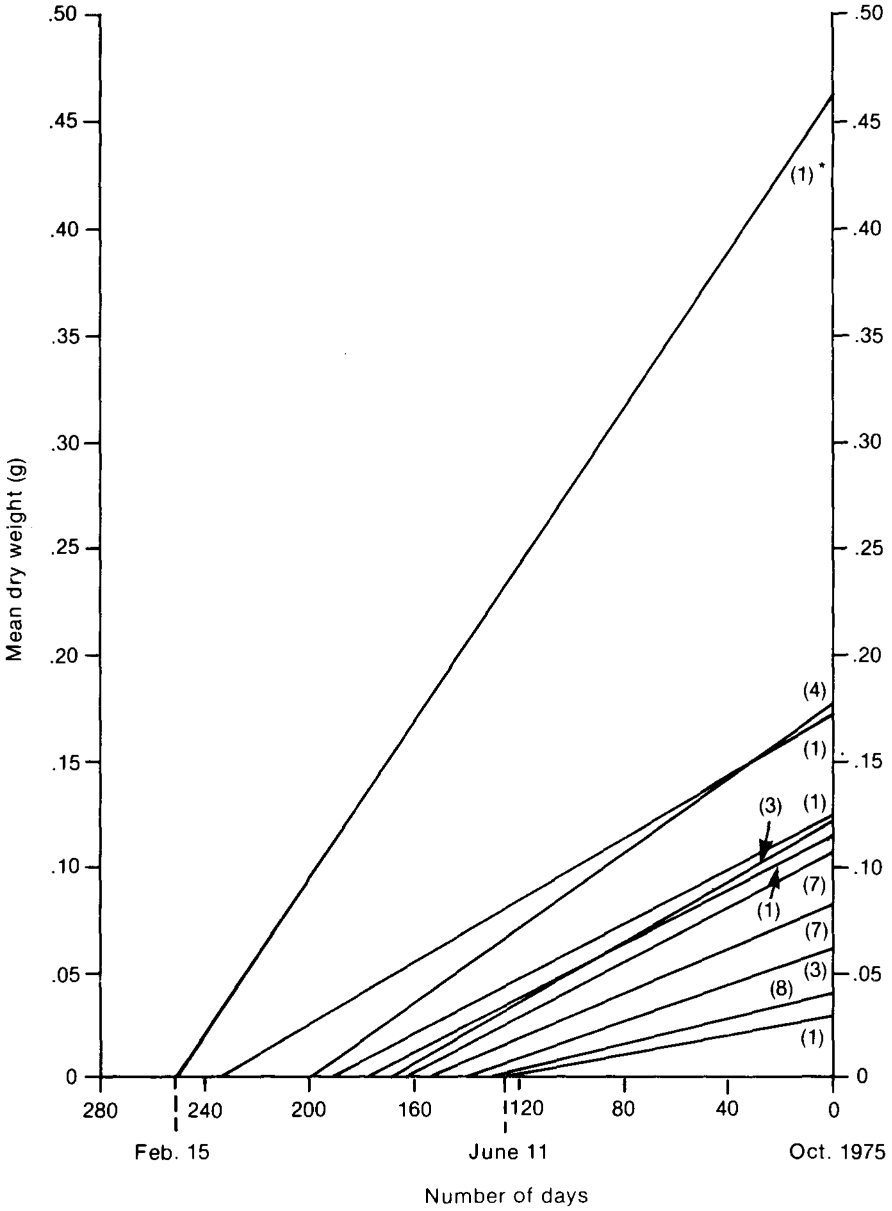

Figure 1—*First-year mean plant dry weight (g) related to duration of growing season in days prior to fall sampling. Numbers in parenthesis indicate number of 20-tree samples included in data.*

A first-year growth rate per day was calculated for each of 37 samples (table 1). First-year dry plant matter production (Y), measured in milligrams per day, correlated highly (r = 0.834) with time, in days, from germination to sampling (X), using the equation Y = -0.912 + 0.009X (fig. 3). The equation accounted for 69.9 percent of the variability in average growth rate. Mean daily growth rates through the first season varied from 0.24 milligram per day for seedlings germinated in June to 1.85 milligrams per day for those germinated in February (table 1).

Similarly, daily growth in the second year, calculated as second-year minus first-year mean dry weight over 180 days for the 36 samples available in the second year, correlated highly with total growing time over the 2 years (Y = -40.095 + 0.150X), accounting for 70 percent of growth variability (r = 0.837) (fig. 3). Second-year growth increments varied from 5.25 milligrams per day for plants from late germination in the first year to 27.00 milligrams per day for plants from earliest germination, associated with cumulative duration of growth of 308 to 432 days, respectively.

Second-year dry-weight increment also correlated highly with first-year mean plant dry weight (r = 0.820). The equation Y = 1 .061 + 9.595X, where Y is total dry-weight increment and X is dry weight of 1-year-old plants, accounted for 67.2 percent of the

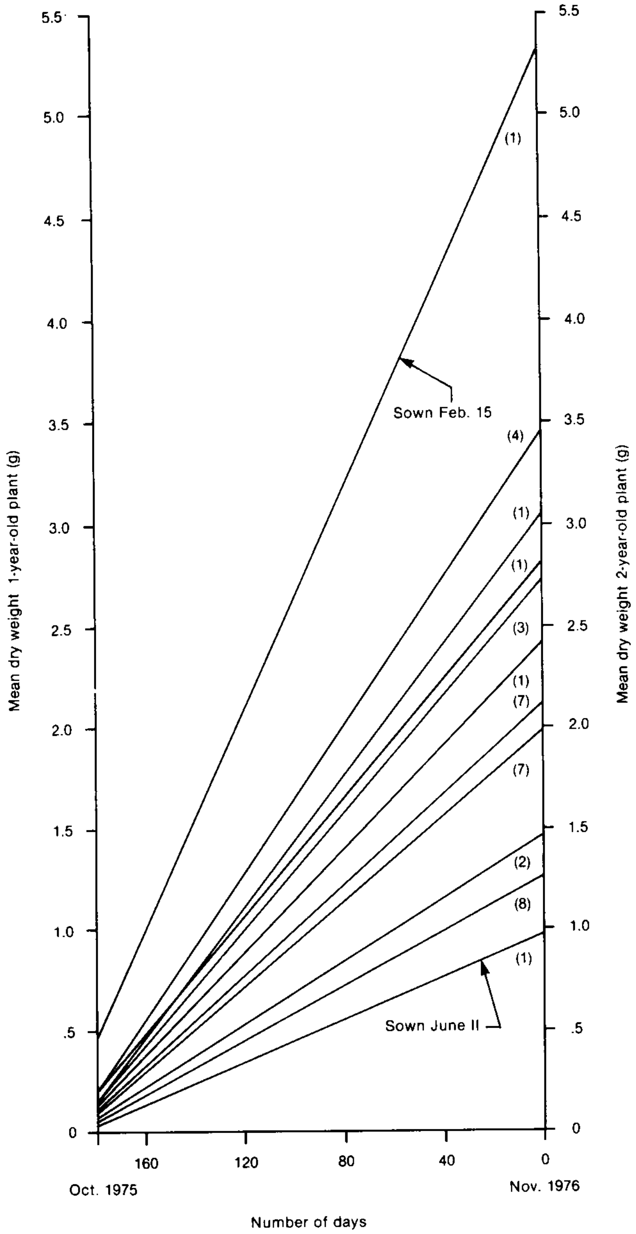

Figure 2—*Second-year mean plant dry weight (g) related to duration of growing season in days prior to fall sampling. Numbers in parentheses indicate number of 20-tree samples included in data.*

variability in mean second-year growth.

In each of the regressions, second- and third-order relationships were tested. In some instances these explained somewhat more of the variability in data. However these regressions were considered to be unduly influenced by limited information in the early weeks of the study. Therefore the linear regressions noted above were considered more appropriate for analysis of results.

Discussion

First-year growth of black spruce in nursery beds was not proportional to duration of growing season alone. Plants from seed germinated in February grew at mean daily rates that were five to eight times those of plants germinated in late May to early June. This increase was associated with a 100-percent increase in duration of growing season. During the second season, a three- to fivefold increase in daily growth was associated with a 40-percent increase in cumulative duration of growth over 2 years.

Scarratt and Reese (5) published growth progressions for jack pine (*Pinus banksiana* Lamb.) container stock to establish the time required to produce shippable stock for different sowing dates. Their data indicated faster rates of growth for seedlings that were germinated early. In fact, their oven-dry weight for 3- to 4-month-old first-year jack pine sown early exceeded that of

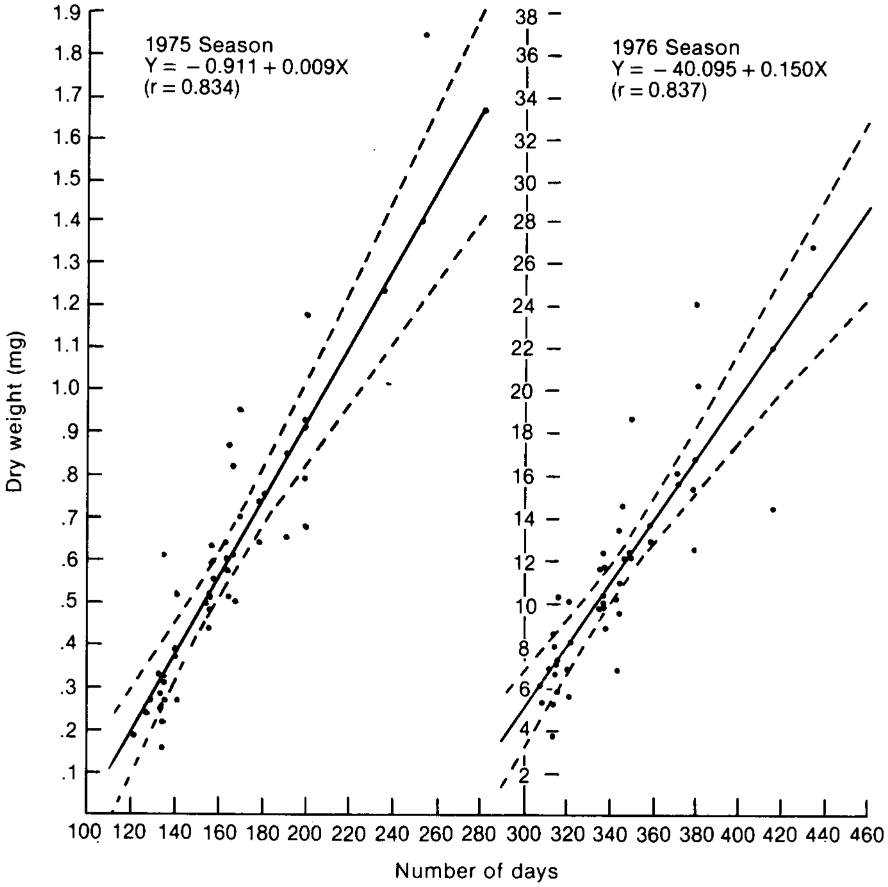

Figure 3—*Mean daily growth (mg) related to duration of growing season (days) with 95 percent confidence limits (2).*

overwintered 2-year-old plants sown late in the first year. Similar growth predictions have been developed for container stock of other species.* Hallett (3) showed different growth patterns for fall-sown black spruce container stock than for stock sown in the early spring.

Second-year growth of black spruce transplants in this study was directly proportional to size of plant at the end of the first season. June germinates grew into 1-gram plants in 2 years whereas February germinates weighed 0.5 gram at the end of the first season and 5 grams after the second season. Factors influencing the size of 1-year-old plants apparently have an important influence on the quality of 2-year-old bareroot shipping stock.

One important component contributing to early vigor is pregermination of seed. If seed are germinated before they are planted in the greenhouse, plants can take full advantage of the growing degree days during the early part of the growing season, when growth is most vigorous. The time saved depends on the pregermination system employed. Use of day-old germinates saves up to a week of greenhouse time; use of cotyledonous seedlings or young trees may save from 4 to 8 weeks. Germination of seed and early plant development can be accomplished in a fraction of the space required for later plant growth. Use of pregerminant seed or cotyledonous seedlings planted in a greenhouse production system produce better stocking.

A heated greenhouse provides an advantage in terms of growing degree-days over a "Finn house" in which auxiliary heat is provided only to prevent freezing. Insulated plastic nursery bed shelters (7) provide less of an advantage in terms of growing conditions but represent lower capital costs and no cost of heat energy. In each case, sowing pregerminated seed provides more uniform plant development and full initial stocking.

The influence of first-year plant size on rate of subsequent growth is a factor to be considered in production of other stock products. In container production, valuable

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*Sadreika, V. Forestry Resources Bureau, Ontario Ministry of Natural Resources, Toronto (personal communication).

Table 1—*Daily rates of growth relative to date of sowing*

		First-year assessment (1975)				Second-year assessment (1976)				
Sowing date	No. of trays	Length season (days)	Mean plant dry wt (g)	SD	Daily growth (mg)	Cum. length 2 seasons* (days)	Mean plant dry wt (g)	SD	2nd year growth increment (g)	Daily growth (mg)
Feb 15	1	252	0.465	—	1.85	432	5.325	—	4.860	27.00
Mar 2	1	234	.172	—	0.74	414	2.798	—	2.626	14.59
Apr 1/2	4	199	.178	0.043	0.89	379	3.429	0.891	3.251	18.06
Apr 9	1	191	.124	—	0.65	371	3.033	—	2.909	16.16
Apr 22	1	178	.114	—	0.64	358	2.418	—	2.304	12.80
May 1	3	169	.121	.039	0.72	349	2.713	.703	2.592	14.40
May 5/7	7	164	.107	.023	0.65	344	2.108	.483	2.001	11.12
May 13/15	7	156	.083	.010	0.53	336	1.993	.226	1.910	10.61
May 27	3	141	.055	.018	0.39					
	2					321	1.466	.576	1.411	7.84
Jun 4/7	8	134	.041	.018	0.31	314	1.254	.346	1.213	6.74
Jun 11	1	128	.031	—	0.24	308	.976	—	.934	5.25

*Duration of 1975 season + 180 days in 1976.

greenhouse space is often used for two or more changes at different times in the season. Little is known of the effect of time of germination on vigor of outplanted trees. Similarly, production of seedling stock is based on variable germination times through the first season in nursery beds. Later germinates with reduced vigor and a shorter growing season produce smaller 1-year-old plants. This contributes to the variability common in beds of black spruce and adds to the reduced yield and increased cost due to culling.

In the 2-year accelerated transplant system for black spruce described here, trees from early sowings grew to a size comparable to 3-year-old bareroot nursery stock standards in Ontario (4). Rapid early growth due to early germination formed a major component of this success. Pregermination of seed is one economical means of improving on germination time in this or any stock system, thereby reducing the space and heating energy required for growth during the coldest period in the production schedule.

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Cutting Stratified Seed of Western White Pine *(Pinus monticola* Dougl. ex D. Don) To Determine Viability or To Increase Germination

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Ungerminated, but viable, stratified western white pine (Pinus monticola *Dougl. ex D. Don) seed will germinate after the side of the seed is cut, exposing the gametophytic tissue. Germination of stratified but uncut seed from several trees averaged 21 percent, ranging from 10 to 30 percent. Germination of stratified and cut seed from the same trees averaged 80 percent, ranging from 20 to 93 percent.* Tree Planters' Notes 37(1):25-26; 1986

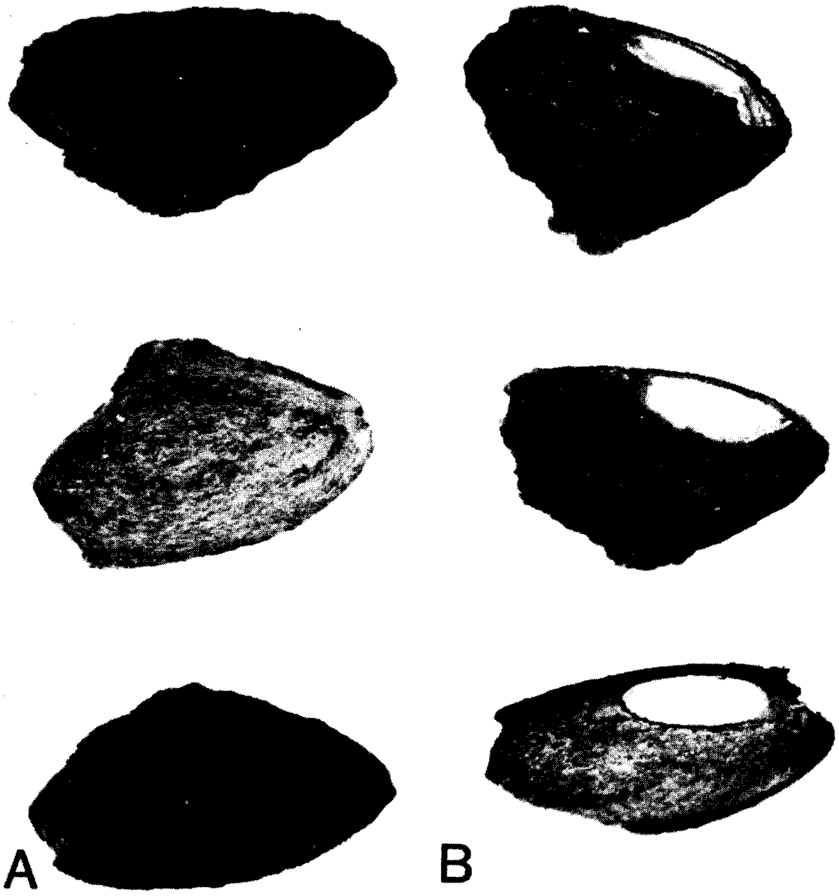

Figure 1A—*Intact seed.* **B**—*Seed cut on side; notice that cut is made into gametophyte tissue.*

Germination of western white pine seeds is often slow and erratic, even after the recommended stratification procedures (90 to 100 days, with constant moisture at 3 °C) are followed (2). Consequently, one is left wondering if the seed was viable, or if something went wrong with the stratification treatment.

In some of our earlier work, we have induced germination of seed that had been stratified and sown by cutting a small sliver from one side of the seed. Poor germination of a recent test made it necessary to cut seed to improve germination. The purpose of this note is to share this procedure with others.

The seed is cut along one side of the seed to remove a small sliver of the seed coat, membrane, and gametophytic tissue (fig. 1). One-sixteenth of an inch can be cut carefully from the radicle end of the seed. A cut at the opposite end results in abnormal germination; namely, the cotyledons emerge through the cut end. Also, the cut must pierce the membrane between the seed coat and gametophytic tissue, or germination will not occur. The membrane, which consists of the inner layer of cells of the integument, appears to the critical structure restricting or preventing germination for this type of dormancy.

One hundred and seventy-five seed from 35 seed lots were sown on May 2 in 10-cubic-inch containers. The seed had been given 45 days of cold-wet stratification. (1). After *28* days of incubation in a warm (70 °F) greenhouse, only 31 percent of the seed germinated (table 1). Therefore, we dug up an

Table 1—*Germination of intact and cut seed of western white pine in 35 seed lots*

	Germination	
	No.	%
Intact seed (6125 seed sown, 175/lot)		
28 days of incubation	1,928	31
49 days of incubation	2,107	43[a]
Cut seed (37/lot)[b]		
21 days of incubation	906	71

[a] Total seed adjusted by seed cut, i.e., 6125 − 1270 = 4855.

[b] Intact seed were cut 23, 24, and 25 days after incubation.

average of 37 seed per lot, cut the seed on the side as indicated in figure 1, and replanted them in the same container. After 21 days of incubation, average germination of the cut seed was 71 percent. Meanwhile, 179 intact seed germinated, which equaled 43 percent after adjusting total seed for number of seed cut. Some seed lots responded more than others. For example, 90 percent of the seed of one seed lot germinated after cutting, compared to only 1 percent when intact.

With the cutting procedure, one can readily determine viability and germinability of stratified seed, and can thus assign the cause of nongermination either to poor quality seed or to the failure of the stratification procedure to overcome seed dormancy factors. The number of germinates from some small seedlots from which a minimum number of seedlings is required can be increased with this procedure. Because the procedure is so labor-intensive, it would probably not be economical for large-scale use, but a mechanical device might be developed to accomplish the task.

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A Soil Moisture Control System for Greenhouse Plant Stress Studies

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A greenhouse soil moisture control system for imposing stress levels is described. Moisture stress in this system results from opposing tensions between a moisture source and a vacuum pump and evapotranspiration. Tree Planters' Notes 37(1):2732; 1986

In greenhouse experiments investigating competition among plant genotypes, plants are generally exposed to different levels of nutrients and allelopathic phytochemicals. Because nutrient availability and the effects of phytotoxins depend on the availability of soil water, control of soil water or moisture stress is imperative. This paper describes a tension lysimeter system designed to maintain two predetermined levels of negative pressure on a soil supporting a large number of seedlings. In this system, soil moisture content is controlled by a balance between evapotranspiration and a vacuum imposed through a ceramic cup in the bottom of the soil profile and moisture moving in response to tension through another ceramic cup in the center of the soil profile. Buffer tanks are used to maintain static tension and to minimize vacuum surges. The system insures drainage in the bottom of planting chambers and serves as a supplementary watering system.

As tested, the system supplied between 45 and 75 percent of total water requirements needed to maintain -0.05 and -0.01 megaPascals (0.5 and 0.1 bars, respectively) soil moisture stress levels. Modifications to decrease supplementary watering can easily be made and are described. The stress levels can be changed as needed.

Description of the System

Tension lysimeters rely on a moisture gradient for movement of water through the soil profile. The moisture gradient in this system results from opposing tensions between a moisture source and an imposed vacuum and evapotranspiration.

The system consists of a series of 32 experimental chambers in a greenhouse with partial environmental control (fig. 1). Each chamber measures 61 by 61 by 61 centimeters (outside dimension) constructed with 1.9-centimeter-thick plywood; it has rabbeted, caulked, and cross-screwed joints, and is painted on the inside with a roofing compound to prevent leakage (fig. 2). The floor of each chamber is recessed 1 centimeter into the sides and sloped 2.54 centimeters to minimize stagnation in the bottom of the box. The chambers are placed on 7.6- by 8.9centimeter frames that are 1.3 centimeters higher on the side perpendicular to the 4 percent slope of the chamber floor; the result is that one corner of each chamber may serve as a point of moisture accumulation, although accumulation would not be expected at these soil water contents except during wetting-in.

A standard 1.3-centimeter CPVC (chlorinated polyvinyl chloride) male pipe adaptor is used as a bulkhead union in the lower corner of each chamber; a 2.23-centimeter-outside diameter (o.d.) ceramic cup (0.1 megaPascal, standard flow, Soil Moisture Equipment Corp. No. 655X1-BIM1; 1 megaPascal = 10 bars) is attached to the inside and is closed with a rubber stopper on the outside. One end of a length of plastic laboratory tubing (Nalgene) (0.64 centimeter o.d. by 0.8-centimeter wall thickness) is inserted through the rubber stopper with the other end of the tubing connected to a 1-liter drainage bottle placed horizontally next to the base of each chamber; a second tube in this bottle is connected to a vacuum manifold. The vacuum creates a negative pressure in each bottle. This vacuum controls the soil moisture tension in each corresponding chamber (fig. 2).

The negative head pressure in the bottle is also used to control the watering system. A third tube connects each horizontal bottle with a water-filled bottle hanging upside down over each chamber; the vacuum head pressure tube in the hanging bottle must be above the fluid level of the water supply. Another tube from each hanging bottle is connected to a rubber stopper in a 46-centimeter-long, 3.8-centimeter-o.d., schedule 40

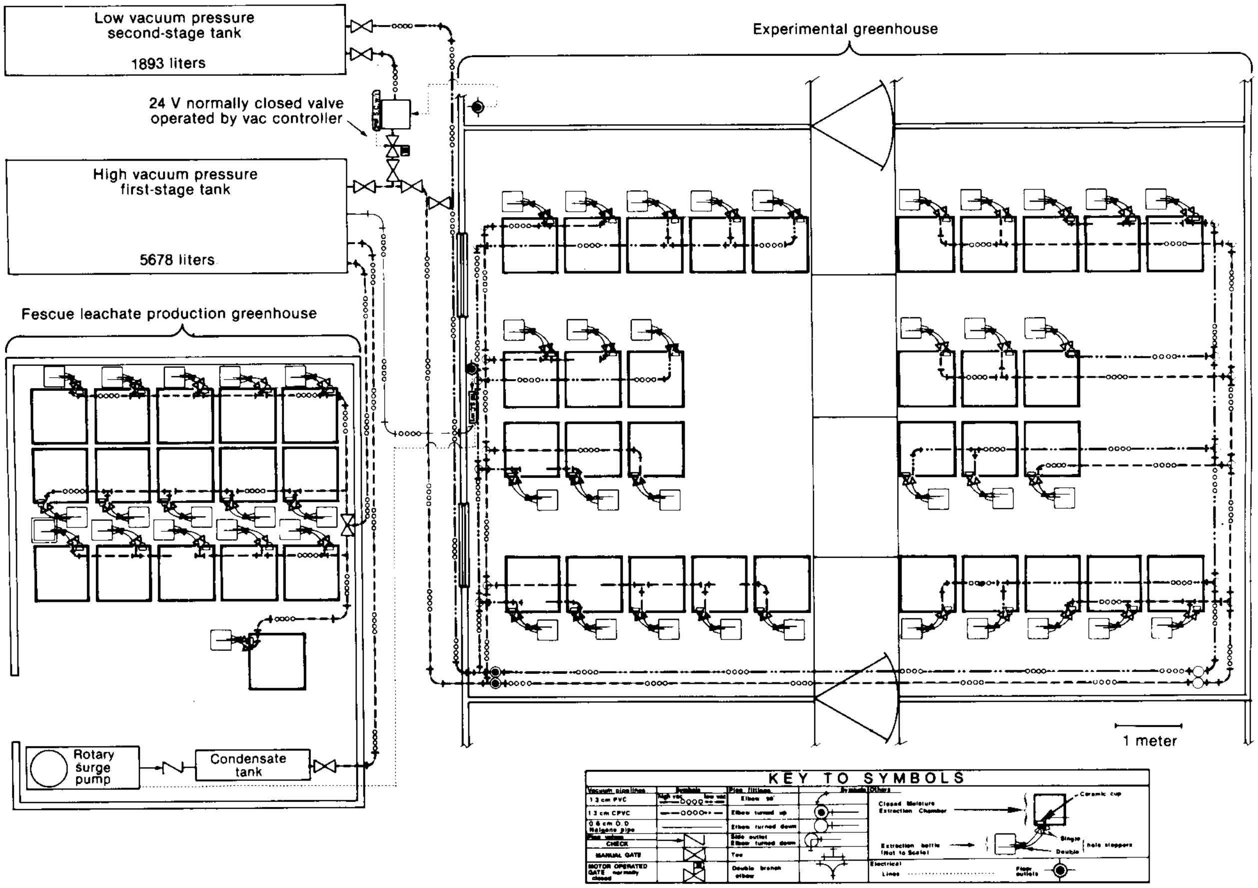

Figure 1—*Schematic diagram of chambers and soil moisture control system. (The fescue leachate production greenhouse on the left was part of another experiment.)*

PVC (polyvinyl chloride) pipe with a 5.2-centimeter-o.d., 0.05-mega-Pascal-tension, high-flow porous ceramic cup (Soil Moisture Equipment Corp. No. 653X3-B.5M2) on the other end (fig. 2). The pipe with the ceramic cup is inserted into the soil at a 45° angle to insure the vertical collapse of the soil on the ceramic cup after the soil is watered-in; a hole of an appropriate size must be evacuated in the soil and some fine silica (particle size < or = 250 µm) added to this hole before the pipe and its ceramic cup are positioned in the soil.

When properly positioned, this ceramic cup is approximately in the center of the soil profile in each chamber. Water enters the soil through this ceramic cup when the moisture tension in the soil increases beyond that imposed by the smaller ceramic cup in the bottom of the chamber. Therefore, the moisture content of the soil is governed by a balance between the vacuum imposed in the bottom of the chamber and/or evapotranspiration and the moisture provided by the ceramic cup in the center of the soil (fig. 2).

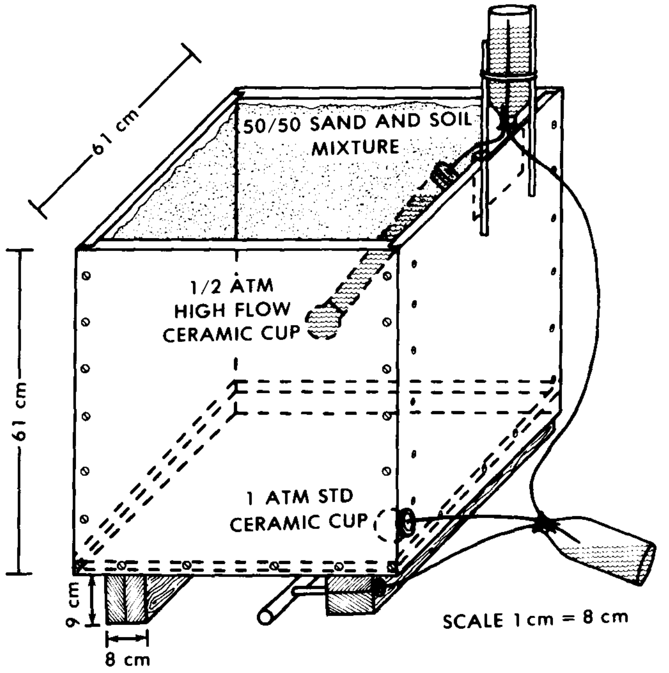

Figure 2—*Diagram of experimental chamber with moisture control system.*

The desired moisture stress is created by means of a rotary vacuum pump. We used a Surge Alamo Model 20 (566 liters per minute, 20 cubic feet per minute), which is commonly used by the dairy industry. In our system two stress levels were imposed, -0.05 and -0.01 megaPascals. The vacuum pressure levels are regulated by electrical vacuum controllers attached to buffer tanks; both vacuum controllers are 24-volt diaphragm microswitches (fig. 3). The purpose of the buffer tanks is to create a large enough vacuum reservoir to keep a static tension on the moisture system with a minimum of vacuum surges. The high stress-high vacuum level results from a direct connection between a 5678-liter (1600-gallon) tank (approved by the American Society of Mechanical Engineers, or ASME) and the vacuum pump. The diaphragm microswitch attached to this tank normally remains open and is activated by a drop in vacuum in the tank. The low stress-low vacuum level is maintained by a second-stage 24-volt controller which regulates an in-line solenoid value between the first- and second-stage buffer tanks. The switch normally remains closed. The second-stage tank has a 1892-liter (500-gallon) capacity and is also approved by the ASME (fig. 2).

Each buffer tank is attached to a PVC feeder line [inside diameter (i.d.) 1.7 centimeters]; feeder lines are in turn attached to CPVC manifolds (i.d., 1.2 centimeters) distributing the vacuum to experimental chambers. A third tank, in-line between the first-stage buffer tank and the vacuum pump, forms a condensate trap to prevent moisture from entering the pump (fig 2).

The soil used to fill the chambers was a uniform 1 to 1 mixture (by volume) of silty clay loam and medium-textured river sand. The sand was used to reduce the moisture gradient in the soil profile. Before the chambers were filled with the soil mix, approximately 0.7 kilogram of fine silica was placed around the small ceramic cups in the bottom of each chamber. The silica maintains continuity of capillary action between the soil and the ceramic cups. The soil in the chambers was watered-in from above over a 1-week period until field capacity was attained.

The effectiveness of the moisture control system was evaluated by weighing the soil-filled chambers biweekly. At the beginning of the experiment each chamber contained 256 kilograms of soil mix at 16 percent moisture content (on a dry-weight basis). Changes in chamber weight were attributed to soil moisture content changes and seedling growth. Because total seedling weight per chamber after one season's growth was negligible relative to the weight of the soil,

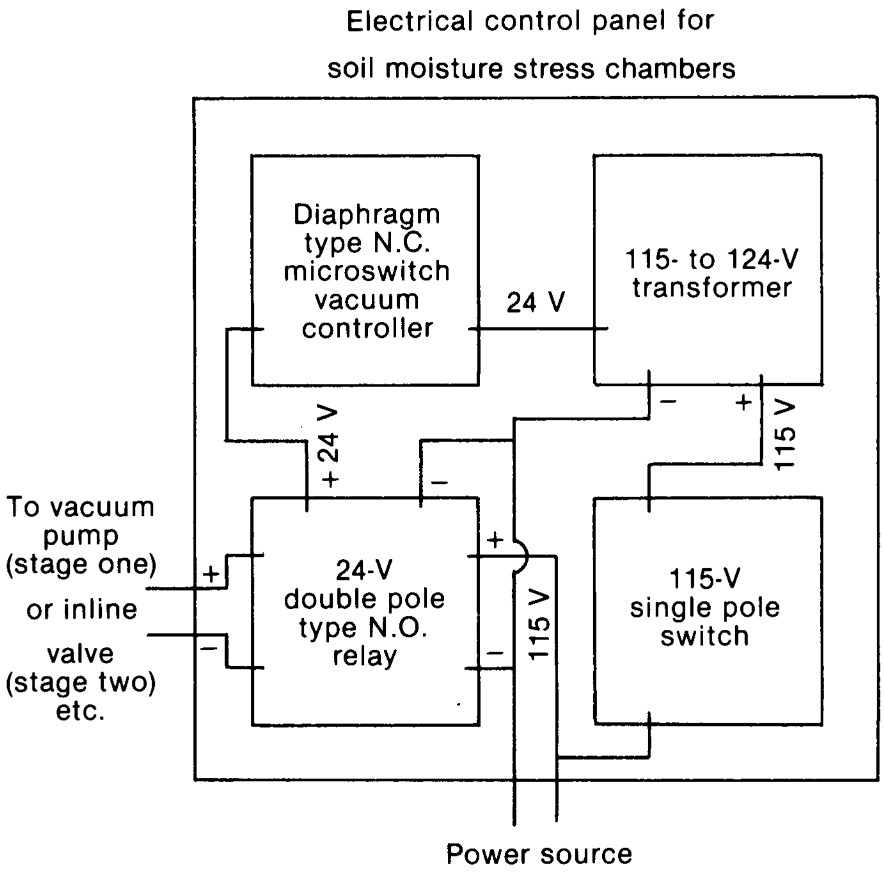

Figure 3—*Electrical control panel for soil moisture stress chambers.*

all weight changes were attributed to moisture content.

A steel cradle for lifting, moving, and weighing the soil-filled chambers was built with 5.0-centimeter-o.d. square steel tubing with 3.176-millimeter wall thickness; within the cradle a steel yoke supports two chain harnesses that can be attached to the chamber (fig. 4). The chambers are weighed by attaching an electronic transducer load cell (W. C. Dillon and Co. Model Z, 454-kilogram capacity, ± 0.23-kilogram accuracy) between the yoke and the cradle.

Performance of the System

The main objective of this system was to maintain differences between two soil moisture stress treatments. This was done by applying -0.01 and -0.05 megaPascal of vacuum tension to the soils in the low-stress and high-stress treatment chambers, respectively. The chambers contained black walnut seedling planted as germinating seed in April and grown for 20 weeks through August 1983. Measurements began approximately 1 month after planting.

Stress levels resulted in average total evapotranspirational water losses of 37.1 liters per chamber in the -0.01 megaPascal treatments and 13.5 liters per chamber in the -0.05 megaPascal treatments for the 4-month measurement period with 30 black walnut seedlings per chamber. Because the low-stress treatment also resulted in substantially faster growth (seedlings growing in the low-stress treatment were 48 centimeters in total height and 13 grams dry weight after 20 weeks versus 36 centimeters in height and 7 grams dry weight in the high-stress treatment), the three-fold difference in water loss also reflects greater transpiration rates on the part of the larger seedlings.

Analysis of variance of percentage of soil moisture (dry-weight basis) disclosed statistically significant differences between the two moisture stress regimes for all measurement periods (table 1). Although the differences in percentage of soil moisture declined until June 28, the minimal difference in soil moisture content between the two moisture regimes at this time (0.58 percent) is within the expectations of a sandy loam soil at these stress levels (1). In a sample of noncompacted soil subjected to the pres-

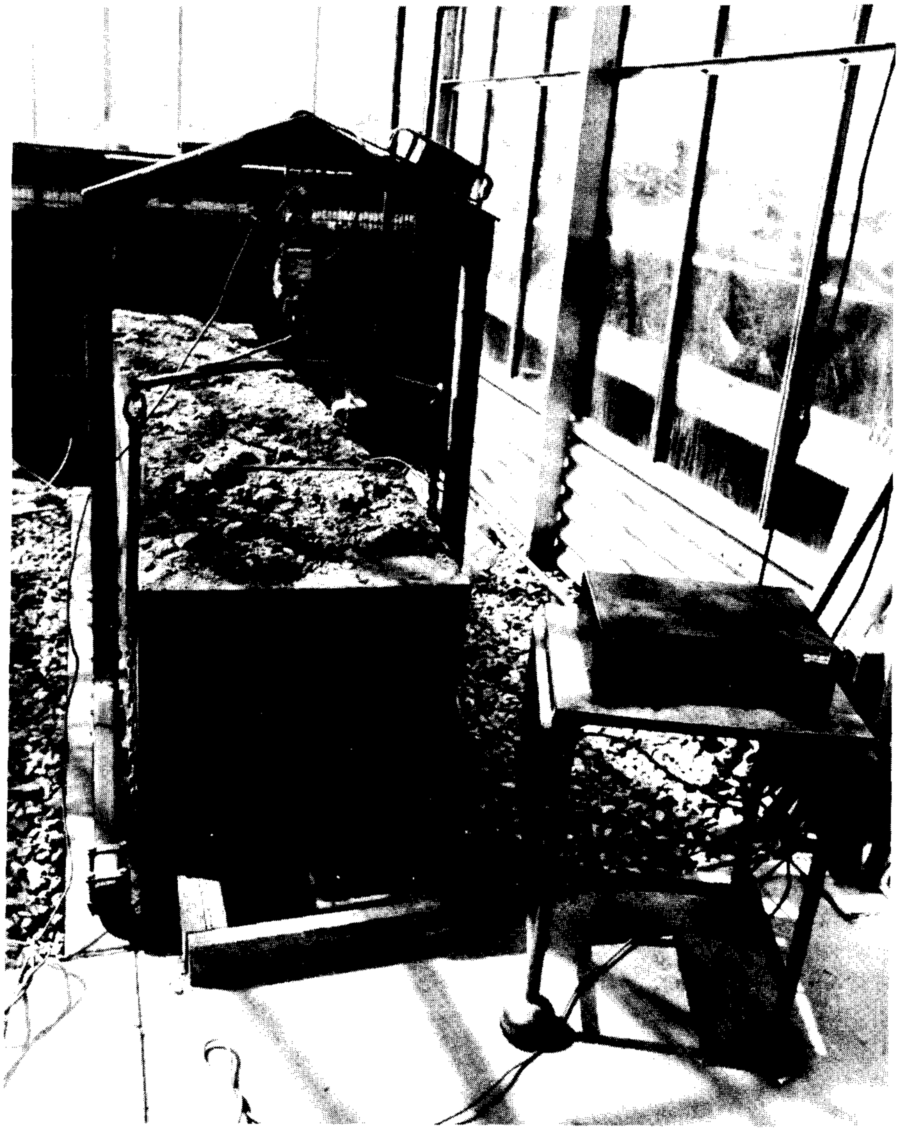

Figure 4—*Cradle, yoke, and harness used to lift, move, and weigh chambers. Digital readout is pictured to the right of the chamber.*

sure plate extraction method, the difference in moisture content between soil under -0.05 megaPascal of tension and that at -0.01 megaPascal was 1.7 percent (see chart at right), a value comparable to the differences measured at the beginning of the study.

Negative pressures (MPa)	**Soil moisture** (%)
-0.01	15.87
- .03	14.56
- .05	14.18
- .10	14.06
- .50	4.47
- 1.00	4.35
-1.50	3.80

In addition, standard deviations around average soil moisture contents per chamber indicate that moisture distribution between chambers was relatively uniform (table 1). Increases in the difference in moisture content between the two stress regimes beyond June 28 are the result of supplementary watering of low-stress treatment chambers to alleviate unexpectedly high evapotranspiration rates encountered at this time. The high evapotranspiration rates resulted from a combination of larger seedlings transpiring greater quantities of water and record high temperatures in the summer of 1983.

The soil in the chambers developed a dry hard crust approximately 2.5 centimeters thick; beneath this surface crust, soil moisture was apparently uniformly distributed. No moisture had stagnated in the chamber bottoms. Because the walnut seedlings were removed from the chambers with intact roots, there was ample opportunity to observe the direction of root growth. There was no indication of root growth toward the center of the chamber (the location of the ceramic cup that was the

Table 1—*Average percentage of soil moisture per chamber and standard deviation (SD), on a dry-weight basis, for six measurement periods*

	Percentage soil moisture (ave. ± SD)					
Stress level	May 17	June 2	June 14	June 28	July 26	Aug 9
Low (−0.01 MPa)	15.54 ± 0.47	12.90 ± 0.80	10.87 ± 0.91	9.13 ± 0.70	7.55 ± 0.75	9.23 ± 0.72
High (−0.05 MPa)	13.96 ± 0.35	11.80 ± 0.64	10.10 ± 0.74	8.55 ± 0.73	6.65 ± 0.84	6.23 ± 0.74
Differences	1.58	1.10	0.76	0.58	0.90	2.91

water source); thus, we assumed that the moisture permeated the soil uniformly by means of capillary action. Similarly, there was no evidence of faster growth of walnut seedlings in the center of the chambers in contrast to seedlings located in other parts of the chambers.

As stated earlier, the moisture control system provided an average of 37.1 and 13.5 liters per chamber of water in the low-and high-moisture-stress treatments, respectively. Although this was adequate to maintain moisture stress differences between the two treatments, it is evident from table 1 that, due to evapotranspiration, absolute stress levels exceeded the -0.01and -0.05-megaPascal values imposed by the vacuum system. In order to maintain those absolute stress levels, we would have needed to add a total of 13.6 and 16.4 liters per chamber of water to each low-and high-stress chamber over the 20-week experimental period. The moisture control system would have provided 73 and 45 percent of the total water requirement of the low- and high-stress treatments, respectively, if the system had been designed to maintain -0.01 and -0.05 megaPascal of absolute moisture stress.

Conclusion and Recommendations

In summary, the moisture control system described here maintained soil moisture differences between the two stress treatments and provided drainage to prevent stagnation in the chambers. The system also supplied between 73 and 45 percent of the watering requirements; the total watering requirement could probably be provided by a) increasing the size of the water supply bottles and b) providing another ceramic cup in each soil profile. This would increase the efficiency of the system, which depends on the size and number of ceramic cups providing water as well as soil texture, volume, and rate of evapotranspiration. Such systems may be of interest to other researchers dealing with greenhouse experiments in which soil environment must be controlled.

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