A Quality-Control System for Improving Conifer Nursery Stock

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The U.S. Department of Agriculture, Forest Service, has begun a program to develop better quality control in its nurseries, refine nursery practices, and identify gaps in fundamental knowledge. Electronic technology is used to monitor factors affecting production and field performance of nursery stock. Tree Planters' Notes 41(1) 3- 7 ; 1990.

The U.S. Department of Agriculture, Forest Service, which manages about 57 million acres for timber production, currently operates 11 bareroot nurseries (one will be phased out in 1990). Nursery production, which exceeds 100 million seedlings annually, is primarily 2+0 conifer stock. Over the past 8 years, the Forest Service has planted an average of 270,000 acres annually.

The Reforestation Improvement Program (RIP) of the Forest Service is an effort to improve the quality of bareroot seedlings produced in its nurseries. The program was conceived in the early 1980's as electronic technology blossomed and collecting and analyzing enormous amounts of data at moderate costs became feasible. The program could thus provide much more definitive information on problems leading to plantation failures. A team of nursery managers and scientists developed the plan, and plots were established beginning in 1986. This paper describes the objectives, procedures, and current status of the program.

Justification and Objectives

The importance of successful reforestation has become widely recognized. An internal study in 1983 found that even a 10% reduction in reforestation failures would save almost $3 million annually. Less tangible, but very important, are the environmental and social justifications for successful reforestation.

Generally, the goal is to make reforestation more predictable and successful. This will be achieved by reaching the following specific goals:

1. Development of a standardized system for collecting and analyzing data, to facilitate interchange of information among nurseries, research groups, and silviculturists.
2. Increased awareness of seedling biology through testing and observation, to improve the knowledge and skills of those conducting nursery and planting programs.
3. Improved practices to lower the quantities of seed needed, reduce production costs, and increase the consistency of producing high-quality stock.
4. Greater knowledge of nursery environments and seedling physiology, to enhance current research and identify knowledge gaps requiring further study.

Program Organization

A steering committee, which monitors the overall program, consists of an administrator, a nursery manager, a silviculturist, and a scientist, who serves as program coordinator. A team of forestry research scientists and a biometrician helps develop and conduct analysis procedures. Ten nurseries are participating fully (fig. 1). The managers agreed to follow standard data collection and analysis proce-

USDA Forest Service Nurseries

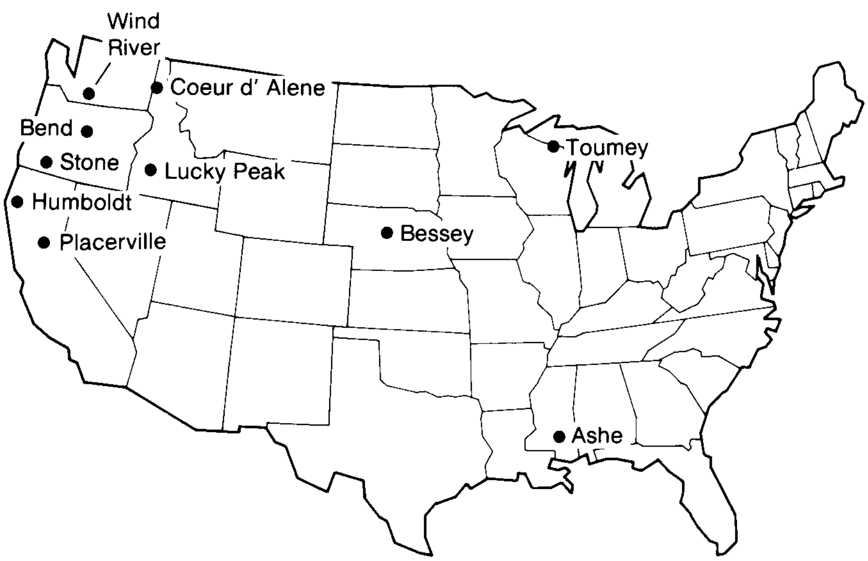

Figure 1—*Locations of National Forest System nurseries.*

dures. Pathologists are conducting pathogen and mycorrhiza analyses. Forest Service districts interested in participating in the outplanting were identified before the seed sources to be monitored were selected.

Establishment of Nursery Plots

Each nursery is testing at least two seed sources of a major species (table 1). Species being used are Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), red pine (*P. resinosa* Ait.), loblolly pine (*P. taeda* L.), longleaf pine (*P. palustris* Mill.), and slash pine (*P. elliottii* Engelm). The same seed lots are sown in 30 m of seed bed in each of 3 consecutive years so that they grow under a variety of weather conditions. Standard cultural practices are used to grow the seedlings.

Treatments performed on the test lots are documented and unusual occurrences noted. Treatments include storage, stratification, and sowing of seed; thinning, weeding, and fertilizing seedlings; applying pesticides to seedlings; and pruning roots and tops. This information will be used in interpreting results.

Environmental Monitoring

Recording weather stations are the heart of the environmental monitoring phase. One station has been installed on a permanent site at each nursery to collect baseline data. A second station has been erected near the test seed beds so that sensors can monitor the weather and soil conditions to which the seedlings are exposed.

Conditions measured are air temperature at 1.5 m above ground level and at the seedling canopy level (20 cm), relative humidity, precipitation and irrigation, wind speed and direction, incoming radiant energy and photosynthetically active radiation, soil surface temperature, and soil temperature and moisture in the seedling rooting zone. The recorder scans the sensors every 5 minutes and records maximum, minimum, and average daily temperatures; average relative humidity, radiation, and wind direction; average and maximum wind speed; and total precipitation or irrigation for each hour. Data stored in easily removable packs are transferred electronically to microcomputers once a month.

Soil physical characteristics were measured once in the test beds. Soil fertility, pathogen levels, and quality of irrigation and ble 1—*Summary of nurseries in Reforestation Improvement Program*

Nursery	Species	No. of lots	Lift date	Ranger district & NF of outplanting
eur d' Alene aho)	Douglas-fir	2	Nov. 87	Bonner's Ferry/Idaho PH
ssey ebraska)	Ponderosa pine	1	Nov. 87	Delores/San Juan Mancos/San Juan
cky Peak aho)	Pondersa pine	2	Spring 88	Council/Payette
mboldt alifornia)	Douglas-fir	1 1	Jan. 88 Jan. 88	Gasquet/Six Rivers Salmon River/Klamath
cerville alifornia)	Ponderosa pine	1 1	Jan. 88 Jan. 88	Weaverville/Shasta-Trinity Pacific/Eldorado
nd egon)	Ponderosa pine	2	Spring 88	Sisters/Deschutes
J. Stone egon)	Douglas-fir	2	Spring 88	Prospect/Rogue River
nd River ashington)	Douglas-fir	2	Spring 88	Wind River/Gifford Pinchot
W. Ashe ssissippi)	Loblolly pine Longleaf pine Slash pine	3 2 2	Jan. 88 Jan. 88 Jan. 88	Evangeline/Kisatchie Black Creek/DeSoto Evangeline/Kisatchie
W. Toumey chigan)	Red pine	1 1	Spring 89 Spring 89	Watersmeet/Ottawa Ontonagon/Ottawa

runoff water are measured periodically.

Environmental conditions to which the seedlings are subjected during lifting, processing, shipping, and planting are carefully monitored, including details such as root exposure times, temperatures, and number of times the seedlings are handled. Temperatures are measured by placing recording devices inside packing bags.

On the planting sites, weather data and factors such as soil characteristics, competing vegetation, animal damage, insect and disease damage, and stand history are measured or observed.

Seedling Measurements

Monitoring begins with establishment of history plots at time of sowing to determine germination rates. These plots are followed until seedlings are lifted to determine numbers of plantable seedlings as a percentage of seeds sown and numbers of cull seedlings by type of problem. In addition, randomly chosen seedlings are measured periodically for height and diameter growth in the seed beds, and detailed observations are made of seedling color and bud activity. As lifting time approaches, root activity and plant moisture stress are measured periodically.

When seedlings are lifted, their height, stem diameter, bud length, and foliage color are measured or observed; and their mineral nutrient status, carbohydrate reserves, root-growth capacity, cold hardiness, and resistance to moisture stress are assessed.

Analyses requiring sophisticated equipment are done by outside laboratories. Root-growth capacity, cold hardiness, and stress tests, however, are done at the nurseries. This is more economical, and the seedlings are not subjected to storage and shipping that might alter their physiology. Also, onsite tests give nursery personnel more appreciation of seedling biology.

Establishment of Performance Tests

Two forest sites were selected for outplanting the test seedlings from each nursery, and each site was equipped with a recording weather station. The sites are ones that can be partially planted in each of 3 consecutive years (table 1).

Site preparation is the biggest problem on many sites. Because one-third of each site must be planted in 3 different years, sites must be prepared so that the conditions of competing vegetation are as similar as possible.

As in the nurseries, environmental conditions, handling, treatments, and seedling performance are recorded.

Data Handling and Analysis

Data collection and analysis are critical phases of the RIP. Each nursery is equipped with a microcomputer, electronic data loggers, and software to make the task as standardized and accurate as possible. Data are transmitted electronically from the weather stations and hand-operated data loggers, or manually through the computer keyboard, to spreadsheet files in the computer. A standard spreadsheet program is used to summarize the weather data and produce monthly and yearly graphs. Indices such as growing-degree days and chilling hours are also calculated.

The information produced is readily available for planning and evaluating day-to-day nursery operations, as well as for building a strong data base to guide future quality control. The data will also be used for scientific analysis.

The RIP is not a single, controlled experiment; instead, it provides comprehensive input-output information on growth of seedlings under a wide variety of conditions. We will make comparisons within the nurseries (for example, weather versus seedling growth in the seed beds), between nurseries and forest sites (seedling size and weight at lifting versus survival and growth after outplanting), and within forest sites (weather on the sites versus survival and growth).

Once we have performance data for all three crops, regression techniques will be used to develop predictive indices. Such indices should help to reduce significantly the number of unexplained failures and to indicate when corrective measures are needed to prevent performance problems.

Current Status of the Reforestation Improvement Program

All three crops have been sown and one or more crops have been outplanted from most of the nurseries. Several nurseries have decided to sow a fourth crop. Nearly 50 spreadsheet formats have been developed, and data are accumulating rapidly.

Implementing the RIP has not been free of problems. Long distances between nurseries have made standardization of procedures and training difficult. The data loggers and weather sensors need closer attention than we had expected, and changes in the data collection and recording procedures have been necessary.

We think, however, that problems have been more than offset by benefits. Nursery personnel are more attuned to nursery environment and seedling biology. Several nurseries have expanded seedling diagnostic procedures beyond their two assigned seed lots. In one instance, test results provided data to help determine the source of a specific performance problem. Stress tests showed that fall-lifted seedlings were capable of breaking bud after similar seed sources had failed to break bud in operational plantings; field conditions or procedures were thus implicated.

We have learned several lessons already. Investing in high-quality weather sensors is important for reliability of operation and accuracy of data. Responsibility for collection and entry of data should be assigned to employees who are apt to stay in place for several years. In addition, employees should be trained in the use of computers beyond merely being able to follow step-by-step procedures.

A Look to the Future

We anticipate that the conclusion of the three-crop RIP plan will mark only the beginning of a higher level of quality control. Despite the increased workload, program participants seem eager to continue monitoring at a reduced but significant level. Procedures will probably not become fully set until near the end of the three crops. We plan to publish our experience and findings in enough detail so that others can use them to improve their nursery programs.

Once an interactive data base for quality control and decision support has been. developed and research has filled gaps in knowledge, we should be well on our way to tailoring nursery stock for particular planting sites and reforestation situations.

Container Hybrid Pines Survive on a Harsh Dam Site

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The scar left after the construction of Trinity Dam in northern California is an extremely harsh site. It was successfully revegetated by planting and fertilizing containerized seedlings of a knobcone x Monterey pine hybrid (Pinus attenuata x Pinus radiata). Fertilization at the time of planting increased the growth of seedlings, but also made them more susceptible to injury from deer and late-season frost. Tree Planters' Notes 41(1):8-14; 1990.

Trinity Dam, which regulates the flow and stores surplus water of the Trinity River in northern California, is an earthfill structure 538 feet high with a crest length of 2,450 feet. The dam forms Clair Engle Lake, which has a storage capacity of 2,448,000 acre-feet. The dam was constructed of earthen material taken from 75 acres of mountainside immediately downstream of its location. The use of this material was convenient and also reduced the hazard to the power plant and spillway from a potential slide area.

However, the removal of all topsoil from the site left a visual scar that contrasts dramatically with the adjacent undisturbed forest (fig. 1). Unfortunately, since completion of the dam in 1962 until now, virtually no natural vegetation has become established in the disturbed area. Since 1968 the USDI Bureau of Reclamation has tried to revegetate this slope with different tree, shrub, and grass species. To establish vegetation, the bureau has tried hydroseeding and planting, along with mulching and irrigating. It found a knobcone x Monterey pine hybrid (*Pinus attenuata* Lemm. x *Pinus radiata* D. Don) to be the most promising species. However, when several thousand seedlings of this hybrid were planted, often only a few hundred seedlings survived until the end of the first growing season.

Much of the scar was devoid of vegetation even after being planted two or three times. In 1983, the size of future plantings was limited until methodology could be developed to improve survival and growth rates of knobcone x Monterey pine seedlings.

This paper describes the results of a joint study between the USDA Forest Service and the USDI Bureau of Reclamation to determine the effects of stock type, fertilizer, and planting season on the survival and growth of knobcone x Monterey pine seedlings at Trinity Dam.

Materials and Methods

Site. The scar at Trinity Dam is an extremely harsh site. Its aspect is west; slopes are 40 to 60%. Because all of the top soil was removed, what remains is skeletal material. Generally, only the C horizon is present. The surface material is extremely rocky; only limited amounts of fine particles are present to hold moisture and provide nutrients. Precipitation averages about 35 inches annually, and only about 10% of this falls between April and September. The availability of soil moisture for plant growth at the site is further diminished because of an extensive subsurface drainage system installed in 1968 to reduce the possibility of slope slippage. Maximum temperatures during summer are often above 100 °F; minimum temperatures during winter are often below 30 °F. Late frosts, such as one that occurred in April 1986, may injure flushing terminals of seedlings.

Seedlings. Bareroot and containerized knobcone x Monterey pine seedlings were used in this study. Both stock types were from the same seed source. Bareroot seedlings were grown at the Forest Service nursery at Placerville, CA, using methods worked out while producing 10 earlier crops. Container seedlings were grown at the Forest Service Tree Improvement Nursery at Chico, CA. This was the first attempt to grow knobcone x Monterey pine seedlings in the Leach super cells (9-cubic-inch single cell container). Seedlings of both stock types were 1 year old when planted. At the time of planting, the stems and foliage of bareroot and container seedlings were similar. Seedlings of both stock types were about 10 inches tall with a 0.2-inch basal diameter.

The root systems of the two stock types were very different. The roots of container seedlings were moist because the rooting medium was moist, and they had many white root tips and mycorrhizal roots. As with previous crops, the bareroot seedling roots were dry (little, if any moist packing material was placed in the packing bag) and had few white root tips or mycorrhizal roots. Records indicate that lifting windows and handling and storage methods were standard for seedlings of both stock types.

The potential of bareroot and container seedlings to develop buds and roots was determined by potting 30 seedlings of each stock type and placing them in a greenhouse. Air and soil temperatures and soil moisture were maintained at levels for rapid bud and root development. Thirty days after potting, the rooting medium of peat moss and vermiculite was washed from the roots. Root development was assessed by counting

Figure 1—*Trinity Dam and power house, and the scar left after their construction in 1962, as photographed in fall 1986.*

the number of new roots longer than 0.4 inches and measuring the longest root. Buds were assessed as being dormant, elongating, or flushing.

Experimental layout. The experimental layout in the field was a randomized block design with subsampling. Each of the 4 blocks was about 100 by 120 feet and contained 15 rows of 12 seedlings each. The rows ran across the contours. Spacing was about 8 feet within and between rows. Five of the 15 rows were randomly assigned one of three treatments: (1) fall-planted container seedlings, (2) spring-planted container seedlings, or (3) spring-planted bareroot seedlings. Therefore, each block contained 120 container seedlings and 60 bareroot seedlings. Three of the 5 rows of each treatment were fertilized with about 60 g of 16:20:0 13S granular fertilizer.

Planting and fertilizing. Seedlings were planted in 10- to 12-inch deep holes made with a 4-inch power auger. Only about 1% of the holes could be made without using a pry to help break or displace rocks. Seedlings were removed from the container or planting bag and immediately placed in the hole. Each worker planted both stock types. After the seedlings were planted, a second hole 6 inches deep was made about 3 inches away from seedlings selected to be fertilized. Fertilizer was poured into the second hole and then covered with soil. Planting and fertilizing were done by a forestry conservation crew from the Crystal Creek Correctional Facility.

The fall planting of container seedlings was done in October 1983. The spring planting of bareroot and container seedlings was done in February 1984. Rain ample enough for high seedling survival and growth rates fell before and after both plantings and was also ample enough to cause movement of fertilizer toward and away from the seedlings.

Data collection and analyses. All seedlings were examined at the time of planting and also after the first, second, and third growing seasons to determine stem vigor, height and basal diameter. A seedling was rated as having high vigor if a terminal was present and healthy, and a full complement of healthy needles was present. Data on stem vigor, height, and diameter were subjected to analysis of variance. Statistically significant differences between treatment means were determined by using Tukey's least significant difference (0.05 level) test.

Results and Discussion

Greenhouse testing of growth potential. Survival and growth of seedlings in the field depend on the outcome of an interaction between the quality of stock planted and its environment (2). High-quality stock will initiate shoot and root growth soon after planting. A strong correlation has been found between early bud burst and survival of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings (4). Because seedlings that initiate bud growth early also initiate root growth early, the correlation between early bud burst and survival probably reflects a correlation between early root growth and survival. The relationship between root growth potential and seedling survival has been demonstrated for a number of conifer species (1, 3, 5-8). Rapid root growth is especially critical on harsh sites like the scar at Trinity Dam, where soil moisture and nutrients are primary limiting factors.

Differences in bud and root development of knobcone x Monterey pine bareroot and container seedlings in the greenhouse were observed. The terminal buds on 14% of the bareroot seedlings were still dormant after 30 days in the greenhouse, 16% were elongating, and 70% were flushing. Terminal buds on all the containerized seedlings were flushing. Differences in root development were correlated

Table 1—*Percent of knobcone × Monterey pine seedlings that developed different numbers of roots and average length of the longest new root developed after 28 days of growing in a greenhouse*

	Seedlings with new roots (%)					Average length of longest roots (in)
Stock type	0	1–5 roots	6–15 roots	16–30 roots	>30 roots	
Bareroot	8	19	43	30	0	8.0
Container	0	0	46	54	0	15.5

with differences noted in bud development. Bareroot seedlings that did not break bud generally produced few, if any, new roots. For both stock types, seedlings that broke bud early generally developed more and longer roots than seedlings that broke bud later.

As bud development varied by stock type, so did root development. The number of new roots produced and the average length of the longest root varied by stock type (table 1). Seventy-three percent of the bareroot seedlings developed 6 or more new roots, each longer than 0.4 inches, while 100% of the container seedlings did. The average lengths of the longest roots developed on the bareroot and container seedlings were 8.0 inches and 15.5 inches, respectively.

If the positive correlation between root development under controlled conditions and seedling survival in the field that was identified for other species holds for knobcone x Monterey pine seedlings, the container seedlings should have a higher survival rate than bareroot seedlings. On this harsh site, survival potential of the 27% of the bareroot seedlings that developed 5 or fewer new roots longer than 0.4 inches is probably very low. All the container seedlings developed 6 or more new roots.

The relatively simple operation of potting seedlings and then examining bud and root development after 30 days provided valuable information. Besides indicating variation in seedling quality within and between stock types, potting tests may indicate where problems exist in the reforestation process. If potting results indicate that survival and growth potential are high, yet survival and growth in the field are low, the problem(s) probably occurred in the field. However, if the potting results indicate that survival and growth potential are low, then the problem probably occurred before the seedlings reached the field. Knowing where a problem occurred increases the probability of solving or avoiding it.

Outplanting trials. Survival of seedlings varied significantly by stock type (table 2). By the end of the first growing season, only 46% of the unfertilized bareroot seedlings survived in comparison to 82% of the container seedlings. Survival results from the field planting probably reflect the results from the potting tests. The seedlings that died apparently did not develop sufficient new roots to sustain growth during the long dry summer. Probably all of the seedlings in the 5-or-fewer-new-roots category and about half of those in the 6-to-15-new-roots category died after outplanting. If that is true, then seedlings on harsh sites such as the Trinity Dam scar should develop at least 10 new roots during the first month. No more bareroot seedlings died after the first growing season. By the end of the third growing season, survival of container seedlings decreased to 74%, which was still significantly higher than the 46% for bareroot seedlings (table 2).

Surviving bareroot and container seedlings grew at similar rates (table 2). Seedlings of both stock types were similar in size when planted; they were also similar in size after three growing seasons. The unfertilized seedlings did not thrive, as indicated by the low percentage of seedlings of each stock type that had high vigor.

Table 2—*Survival, high vigor, stem height, and diameter of fertilized (+) and unfertilized (0) bareroot (BR) and containerized (Cont.) knobcone × Monterey pine seedlings planted during the spring at Trinity Dam, CA*

Stock type	Fertilizer	Survival (%)	High vigor (%)	Height: Total (in)	Height: Increment* (%)	Diameter: Total (in)	Diameter: Increment* (%)
First growing season							
BR	0	46 a	55 ab	11.3 a	9	0.23 b	41
BR	+	32 a	61 b	11.6 a	13	0.25 b	56
Cont.	0	82 b	29 a	11.3 a	15	0.18 a	21
Cont.	+	56 ab	69 b	13.0 a	32	0.25 b	68
		(33)	(26)	(2.8)		(0.06)	
Second growing season							
BR	0	46 a	64 ab	15.7 a	39	0.32 ab	40
BR	+	32 a	83 c	17.2 ab	35	0.43 b	70
Cont.	0	75 b	52 a	15.0 a	32	0.29 a	59
Cont.	+	55 ab	74 bc	20.0 b	54	0.46 b	84
		(26)	(18)	(4.3)		(0.11)	
Third growing season							
BR	0	46 a	69 a	19.8 a	26	0.46 ab	44
BR	+	32 a	67 a	23.4 ab	36	0.63 bc	47
Cont.	0	74 b	61 a	19.6 a	31	0.43 a	49
Cont.	+	55 ab	86 b	26.6 b	33	0.71 c	53
		(27)	(16)	(6.6)		(0.19)	

*Percent increase over previous measurement.

Values within the same growing season that are followed by the same letter do not differ statistically at the 0.05 level. Values in parentheses denote the 5% Tukey least significant differences.

Outplanting fertilization trials. For seedlings of both stock types, survival was higher for unfertilized seedlings than for fertilized seedlings (table 2). This may have resulted from fertilizer burn of the root system. Even though the quick-release fertilizer was placed in a hole several inches from the seedling roots, apparently because of the rockiness of the soil and the heavy rains that followed planting and fertilizing, sufficient fertilizer came into contact with the seedling roots to cause injury. Bareroot seedlings were more affected by the fertilizer injury than were container seedlings. A possible explanation is that container seedlings generally developed more new roots than did bareroot seedlings. Therefore, losing some roots to fertilizer injury would not be as detrimental to container seedlings as it would be to bareroot seedlings. The problem of root burn could be avoided by using a slow-release fertilizer.

Fertilizer had a positive effect on seedling vigor, stem height, and diameter, however. Within 3 weeks after application, it was apparent which seedlings had been fertilized. Fertilized seedlings of both stock types were greener and had greater bud extension than unfertilized seedlings. The height and diameter of the container seedlings generally showed a greater growth response to fertilization than did bareroot seedlings (table 2), which again may be explained by the better new growth of the container seedlings.

Effect of fertilization on deer browsing and frost damage. The effects of fertilizer on height and diameter were partially

Figure 2—*Unfertilized (left) and fertilized (right) knobcone × Monterey pine seedlings after the third growing season.*

masked by deer browsing and frost, however. Seedlings were affected differentially by deer browsing and frost, depending on whether or not they were fertilized. For both stock types, the differences in vigor, stem height, and diameter between fertilized and unfertilized seedlings were compounded by deer predation. Deer damaged tops of more fertilized seedlings than unfertilized seedlings, 16 versus 8%, respectively. This may have occurred because fertilized seedlings, with their large, more succulent tips, were more attractive to deer (fig. 2). A late frost at the beginning of the third growing season injured the growing tips of 32% of the fertilized seedlings, compared to only about 5% of unfertilized seedlings. Lateral buds quickly expressed dominance on injured seedlings, however, so apparently little height growth was lost.

Spring planting versus fall planting. The field performance of container seedlings was the same whether they were planted in the spring or fall, as there were no significant differences between planting season and seedling survival rates or between stem height or diameter growth rates. No bareroot seedlings were fall-planted, because no dormant stock was available.

Management Implications

Research indicates that harsh sites such as the scar left after the construction of Trinity Dam can be revegetated without extraordinary methods if

1. **The correct species is planted.** Previous efforts to revegetate the scar indicated that knobcone x Monterey pine seedlings would grow on this site.
2. **Seedlings have high survival and growth potential.** Container seedlings of this hybrid should be planted because they have a higher capacity to develop new roots than bareroot seedlings, and

therefore have a higher capacity to survive and grow. Also, container seedlings can be successfully planted in the spring or fall, whereas bareroot seedlings, because they do not harden enough to allow fall lifting, are available only for spring planting.

3. **Nutrient requirements of seedlings are met.** For rapid establishment of seedlings, a slow-release fertilizer should be applied at the time of planting. A quick-release fertilizer such as that used in the study is not recommended on rocky sites because of leaching, which results in burning of the roots and loss of nutrients. The fertilizer should be formulated to overcome the nutrient deficiencies gaps of the site.

4. **Seedlings are protected against deer browsing.** Fertilized seedlings must be protected from deer because of the increase in browsing following fertilizing. Fertilized seedlings are more susceptible to late frost damage than unfertilized seedlings, but fertilized seedlings also appear to recover faster from injury than unfertilized seedlings.

Literature Cited

1. Burdett, A.N. 1979. New methods for measuring root growth capacity: their value in assessing lodgepole pine stock quality. Canadian Journal of Forest Research 9:63-67.
2. Burdett, A.N. 1983. Quality control in the production of forest planting stock. Forestry Chronicle 59(3) :132-138.
3. Feret, P.P.; Kreh, R.E. 1985. Seedling root growth potential as an indicator of loblolly pine field performance. Forest Science 31(4):1005-1011.
4. Heiner, T.C.; Lavender, D.P. 1972. Early growth and drought avoidance in Douglas-fir seedlings. Res. Pap. 14. Corvallis, OR: Oregon State University, Forest Research Laboratory. 7 p.
5. Jenkinson, J.L.; Nelson, J.A. 1983. 1-0 Douglas-fir: a bare-root planting option. In: Proceedings, Western Forest Nursery Council and Western Nurseryman's Conference; 1982 August 10-12; Medford, OR. Ashland, OR: South Oregon Regulation Services Institute, South Oregon State College: 63-76.
6 Ritchie, G.A.; Dunlap, J.R. 1980. Root growth potential: its development and expression in forest tree seedlings. New Zealand Journal of Forest Science 10:218 248.
7. Stone, E.C.; Norberg, E.A. 1979. Use of root growth capacity in developing propagation regimes, storage criteria, and nursery stock certification. In: Proceedings, Symposium on regeneration and management of young true fir stands; 1979 May 31; Redding, CA. Redding, CA: The True Fir Management Cooperative: 1-35.
8. Sutton, E.F. 1980. Planting stock quality, root growth capacity, and field performance of three boreal conifers. New Zealand Journal of Forest Science 10:54-71.

Epigeous Ectomycorrhizal Fungi of Oaks and Pines in Forests and on Surface Mines of Western Maryland

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Epigeous basidiocarps of ectomycorrhizal fungi were collected for 2 years from oak (Quercus sp.) forests, 1 year from conifer (Pinus sp.) forests, and 1 year from oak and conifer reforested surface mines in western Maryland. Botanical, physiographic, and edaphic data were collected. Two hundred and ninety-one specimens, representing 18 genera and 33 identified species, were obtained. Possible ecological implications for the occurrence of these fungi on these sites are proposed. Tree Planters' Notes 41(1):15-23; 1990.

Reforestation of surface mines is a difficult process. The role of mycorrhizal fungi in aiding the establishment and growth of trees has been well documented (17). Trees that pioneer and invade surface mines and those that regenerate in forest understories usually become colonized in situ with indigenous mycorrhizal fungi. Seedlings to be used in reforestation efforts must also be provided with this vital symbiotic relationship. Seedlings may be raised in nurseries in conjunction with indigenous fungi, inoculated with a prescribed fungus prior to outplanting, or inoculated at the time of outplanting. Successful reforestation efforts depend on the selection of fungus, host, and site in proper combination (5, 6). However, the selection of fungi for specific hosts and site conditions is a process for which guidelines have yet to be established for many situations, especially for temperate eastern forest areas in the United States.

Several investigators have surveyed indigenous fungi and their associated hosts in an effort to explain the ecological implications and significance of the symbioses. Schramm's classic 20-year investigation (27) of pioneering fungi on black wastes from anthracite mining in Pennsylvania yielded valuable information concerning the ecologies of the flora and their interactions with the climate and edaphic properties of these wastes.

Recent studies have been made in beech-maple (*Fagus-Acer*) and conifer forests of Michigan (20), aging birch (*Betula*) forests in Great Britain (22), and in mature and burned jack pine (*Pinus banksiana* Lamb.) forests in Alberta (11). Additional studies have also explored how the rate of plant succession is regulated via mycorrhizae (1) and the contribution of specific and nonspecific plant-fungus associations to forest community dynamics (24).

Wilkins and Harris (30) investigated the influence of precipitation and temperature on the seasonal production of fungi in *Fagus* and *Pinus* forests. The study showed that although precipitation was not an exact equivalent of plant available moisture (PAM), and many fungal species were relatively indifferent to temperature fluctuations, minimum requirements for both precipitation and temperature had to be met before basidiocarps (that is, the fruiting bodies, in this case, mushrooms and puffballs) are produced. Last and others (21) determined a positive correlation between the fruiting of *Amanita muscaria* (F r.) Hooker and rainfall in *Pinus* plantations.

Allen and Hipps (2) found an increase in *Russula emetica* (Schaeff. ex Fr.) Pers. ex Fr. basidiocarps on Norway spruce (*Picea abies* (L.) Karst.) and

Supported in part by the McIntireStennis Cooperative Forestry Research Funds. The authors thank Lorrie Griffiths, Donna Baker, Margaret Favela, Ann Sidor, Lori Graunke, Cynthia Wright, Sola Erickson, Francis Hobbes, and Robert Cire for assistance with the survey; and Drs. Edward Hacskaylo and James Trappe for their support and encouragement.

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests with high moisture, nitrogen, and carbon contents, and especially in shady areas with 29% light. Lange (18) related fruiting to timing and quantity of precipitation and soil water in a Danish forest, and Smarda (28) as reported by Lange (19) ascribed variations in the phenology of fleshy fungi to humidity. Menge and Grand (23) mention that physiological and edaphic factors (that is, soil-related factors) can influence the production of basidiocarps.

This paper describes natural associations between mycorrhizal fungi and their suspected hosts for two forests and two surface mines in western Maryland. Botanical, physiographic, and edaphic data were used to develop possible ecological reasons for the occurrence of these fungi on these sites.

Materials and Methods

Three geographical locations (macrosites) were selected in the two most western adjacent counties of Maryland: (a) Green Ridge State Forest, (b) Savage River State Forest, and (c) two surface mines bordering the Savage River State Forest.

Green Ridge State Forest is in Allegheny County, 6 miles east of the town of Flintstone, MD, on U.S. Route 40 in the Ridge and Valley Province of the Allegheny Mountains. The area consists of 14,000 hectares of an oak-hickory (*Quercus-Carya*) and pine *(Pinus*) forest. The soils are predominately shaly silt loams that are thin, dry, and moderately productive. Elevation ranges from 145 to 622 m. Savage River State Forest is in Garrett County, on the Allegheny Plateau. The area consists of 22,000 hectares of an oak-hickory and pine forest. The soils are predominately stony loams and stony silt loams that are thin, more moist than the soils of Green Ridge, and moderately productive. Elevation ranges from 427 to 938 m. The two surface mines are in Garrett County. They are privately owned and mining was completed in 1971. There was no soil reclamation, but the mines were planted with oaks and pines. The Beener mine is near Barton, MD, east of Savage River State Forest at an elevation of 482 m. The Turner-Clise mine is near Bittinger, MD, west of Savage River State Forest at an elevation of 762 m .

Several microsites were selected to represent the diversity of the forest of each macrosite. Microsites were approximately 0.14 hectares each but had irregular shapes due to physical or botanical parameters that excluded areas not compatible with predominant microsite characteristics. The oak microsites were surveyed periodically for 2 years (August 15, 1981 to August 15, 1983) and pine microsites, for 1 year (August 15, 1982 to August 15, 1983). Survey visits were conducted weekly in the spring and fall and biweekly in the summer, weather and transportation permitting. These areas were traversed and scanned for above-ground fruiting structures (that is, epigeous basidiocarps) of ectomycorrhizal fungi. Slightly raised clumps of leaves or debris were examined for hidden basidiocarps. Below-ground (hypogeous) fungi were noted only when erumpent and thus noticeable without systematic raking.

Basidiocarps (mushrooms and puffballs) were the fundamental specimens on which further detailed data collections were made. Basidiocarps that could be immediately identified were coded. Those not immediately identified were wrapped in waxed paper, stored in an ice chest, and taken to the laboratory for identification, both macroscopically and microscopically, then dried and kept as voucher specimens.

Plastic tags were stapled on the nearest suspected host tree to the basidiocarp location with a designated code of the fungus and date. A soil sample of approximately 500 cm^3 was collected directly under the location of each basidiocarp to a depth of 15 cm. Soil samples were cleared of litter, humus, and stones greater than 2 cm in diameter during collection.

Individual soil samples from all oak and conifer sites were analyzed for soil texture (11, 12) and organic matter (3). The first-year and second-year collections of soil samples within each oak microsite were then combined for analysis of pH (25), base exchange capacity (13), water-soluble nitrate (NO_3^-)-nitrogen (9), and selected elements (13). Plant available moisture (PAM) was determined by the difference in -⅓ bar and -15 bar available moisture (26). Soil conductivity was measured by the procedure described by Bower and Wilcox (8). Sulfur was analyzed by the methods of Bremner and Tabatabai (10). Soil samples within each conifer microsite (second-year collections) were combined for analysis of all the parameters listed above.

General Results

On the oak forest and oak surface mine sites, 91 fungus specimens were collected the first year and 118 the second year, representing 32 ectomycorrhizal species in 15 genera (table 1). The oak forest sites of Green Ridge and Savage River provided 103 and 87 specimens, respectively, each having 22 species representing 10 genera, primarily *Russula, Lactarius*, and *Amanita*. The oak surface mine sites provided 19 specimens representing 5 genera. *Scleroderma citrinum* Pers. and *Pisolithus tinctorius* (Pers.) Coker and Couch were the most common fungus species on oak surface mine sites.

One-year collections from all pine forest and pine surface mine sites provided 82 specimens representing 17 ectomycorrhizal fungus species of 12 genera (table 1). The conifer forest sites of Green Ridge and Savage River provided 6 and 29 specimens, respectively, each having 4 and 12 species, representing 4 and 8 genera. *Lactarius* and *Amanita* were most common on Savage River conifer forest sites. Conifer surface mine sites provided 47 specimens representing 9 species of 7 genera where *S. citrinum*, *P. tinctorius*, *Amanita muscaria*, and *Suillus* species were most common.

Specific Results and Discussion

The following discussion refers to the data in tables 1-3, with particular reference to microsites (the codes are listed in table footnotes).

A. *Scleroderma citrinum* was most common on SM-1 and SMC-1. These adjacent sites had nearly identical weather patterns but dissimilar soils. Plant available moisture (PAM) values for these sites are of the lowest of all microsites. SM-2 also had low PAM, although *S. citrinum* was scarce there. SM-2 differs from SM-1 and SMC-1 in that the nutrients B, Si, Zn, Fe, Ni, P, Mn, Mg, K, and NO_3^--nitrogen were lower in concentration. Therefore, although S. citrinum is a primary and aggressive pioneer species on surface mines as well as a resident of natural undisturbed temperate forests (5), it and/or its host may have required more available nutrients than found at SM-2.

B. *Pisolithus tinctorius* was found associated with oaks and pines but only on surface mines (SM-1, SM-2, and SMC-1). It is considered an aggressive pioneer and unlike *S. citrinum*, appeared to be site specific.

C. *Russula* species were most common on oak forest sites. Aluminum, iron, and silicon contents of oak site soils were very low compared to pine sites. GR-2 and GR-5 had low *Russula* populations and were unevenaged forests dominated with chestnut oaks (*Quercus prinus* L.). *Russula emetica* (Schaeff. ex Fr.) Pers. ex Fr. was scattered among both GR and SR oak forest sites, and in particular, was very common on GR-7 and SR-5. GR-7 had the lowest soil copper over the other GR's but had scarlet oaks (*Quercus coccinea* Muenchh.). SR-5 had highest calcium over other SR sites. The copper and calcium levels

Table 1—*Total number of ectomycorrhizae-forming fungi specimens collected on forest and surface mine sites of oaks and conifers in Western Maryland*

Ectomycorrhiza-forming fungus	Oak																	Pine								Total specimens per species
	SM		GR							SR							SMC	GRC			SRC					
	1	2	1	2	3	4	5	7	8	1	2	3	4	5	6	8	1	1	2	3	1	2	4	5	6	
Amanita spp.				1				1																		2
A. brunnescens Atk.											1												1			2
**A. gemmata* (Fr.) Bertillon				1																						1
**A. caeserea* (Fr.) Schw.									1																	1
**A. chlorinosma* (Austin) Lloyd							1				1															2
**A. citrina* (Schaeff.) S.F. Gray					1			1					3			3										8
A. cokeri (Gilbert & Kuhner)												1														1
A. flavioconia Atk.																								1	6	7
**A. muscaria* (Fr.) S.F. Gray																	5				1				2	8
**A. phalloides* (Fr.) Secr.			1			1																				2
**A. vaginata* (Fr.) Vitt.			1					2				1														4
**A. virosa* Secr.			1	1	1		6			1	1													1	1	13
Boletus spp.												1				1										2
B. affinis Pk.				1		1																				2
**B. badius* Fr.																									1	1
**B. chrysenteron* Bull. ex St. Amans						1					1			1												3
**B. piperatus* Bull. ex Fr.																1									1	2
Calostoma cinnabarina Desvaux										2																2
Cantharellus cibarius Fr.			1																							1
**Cortinarius albo-violaceus* (Fr.) Fr.			1							1	1						1								2	6
Hebeloma spp.	1																									1
**Laccaria laccata* (Scop.:Fr.) Cooke																									2	2
Lactarius spp.			4					1					2			1										9
**L. chrysorheus* Fr.			1					1		2		5	1	1	2					2				6	1	22
**L. piperatus* (L. ex Fr.) S.F. Gray				2	4			4				1														11
Limacella spp.										2	1	1														4
**Phyllophorus rhodoxanthus* (Schw.) Bres.								1			1															2
**Pisolithus tinctorius* (Pers.) Coker & Couch	2	4															9									15
Pluteus spp.								1																		1
**Rhizopogon nigrescens* Coker & Couch																	1									1
Russula supp.	2		8	1	5	3	2	7	6	4	1	1	1	1		4										46
**R. emetica* (Fr.) Pers.		1	2	1	1	2		10		3	4	2		8	4											38
R. fallax (Fr.) Britz.							2	1		3				1						1						8
**R. virescens* (Schaeff. ex Krombh.) Fr.										1																1
**Scleroderma citrinum* Pers.	7	1	1	1	1				1	3							11		2		1					29
**Strobilomyces floccopuss* (Vahl ex Fr.) Karst.								2	1									1								4
**Suillus granulatus* (L.: Fr.) O. Kuntze		1								2	1	1					6					1				12
**S. americanus* (Pk.) Snell ex Slipp & Snell																	7									7
**S. luteus* (Fr.) S.F. Gray																	4									4
**Thelephora terrestris* Ehrhart ex Fr.																	3								1	4
Total specimens/site	12	7	21	9	13	8	11	32	9	24	13	14	7	13	6	10	47	1	2	3	2	1	1	8	17	291

* = known ectomycorrhiza-forming fungi, others are suspected ectomycorrhiza-forming fungi.
Sites are coded by areas and site numbers. SM = surface mine, GR = Green Ridge State Forest, SR = Savage River State Forest. Some site numbers were omitted. Note where species names are not provided, spp. indicates fungi of known genus but unidentifiable species.

between these two sites (GR-7 and SR-5) were opposing, and almost all other variables were dissimilar except they had in common sandy loam soils. None of the other GR and SR sites had sandy loam soil except GR-5. GR-5, even though it had a sandy loam soil, had no R. *emetica* but the lowest plant available moisture (PAM) of all oak forest sites.

D. *Suillus* species were most common on SMC-1 and apparently were pioneer fungi with a preference for pine hosts and are not known to associate with hardwoods (29). Even though *Suillus granulatus* (L. ex Fr.) O. Kuntze was a resident of SR-1, SR-2, and SR-3, these three sites had a few scattered pine seedlings in the understory, suggesting that these might be the symbiotic link rather than the oaks.

E. *Lactarius chrysorheus* Fr. was most common on SR sites rather than GR sites, and even though PAMs were similar, SR sites were cooler (higher elevations) and received more precipitation. *Lactarius chrysorheus on* SR-3 and SRC-5 was abundant although these two microsites had a few variables in common. *Lactarius piperatus* (L. ex Fr.) S. F. Gray were more frequent on GR sites over SR sites which was in contrast to the presence of *L. chrysorheus for* these sites (table 1).

F. *Amanita* species primarily inhabited oak forests. *Amanita virosa* Secr. was common on GR-5, a site with the lowest PAM of all GR sites. *Amanita citrina* (Schaeff.) S. F. Gray populated SR-4 and SR-8 that had similar variables (chestnut oak hosts; PAM, K, pH and Na levels). However, *A. muscaria* pioneered on SMC-1, and *A. flaviconia* Atk. inhabited SRC-6, a site with the co-component dominating host as Norway spruce.

Conclusions

We can make no conclusions from these data without the use of pertinent phenological characterizations and repetitious samplings over a longer period of time. However, other authors [Arnolds (4) and Fogel (14), as reported by Bills et al. (7)] have concluded that up to 98% of the potential fungal species were observed in a 3-year period and Gardner and Malajczuk (15) determined that there is a close relationship between the fruiting of fungal species and the development of specific ectomycorrhizal root structures in *Eucalyptus marginata* J. Donn ex Sm. Tarrah. The occurrence of basidiocarps indicates a greater number of symbionts than the observations of mycorrhizae alone (11). Danielson also determined that estimates of mycorrhizal fungal numbers would be low unless collections were made over long periods of time.

It appears that ectomycorrhizal fungi may or may not be host specific and/or site specific (11, 16, 22), although Bills (7) reported fungal species diversity was greater in hardwoods. Thus, forest tree regeneration planning must not only consider the matching of tree species to the site but include the compatibility of the ectomycorrhizal fungi *in situ* or introduced to the host and site for effective symbioses. The evidence from this and other studies supports early and late successional mycorrhizal fungi, and that certain species characteristically occur in early stage development and others in late stage development. The question would be then whether to use earlier or latter succesional fungi. Further studies are warranted to categorize host fungus/site combinations for prescription planting or reforestation on surface mines and other disturbed sites.

Table 2—*Characteristics for oak forests on surface mine sites and two state forests in Western Maryland*

	SM		GR							SR						
Site characteristics	1	2	1	2	3	4	5	7	8	1	2	3	4	5	6	8
Elevation (m)	482	762	244	299	305	323	475	293	323	847	670	725	812	768	756	774
Slope (%)	5	5	10	8	5	20	6	18	3	4	6	4	12	8	9	5
Basal area (m^2/ha)	6	3	46	46	48	40	56	43	46	51	31	54	34	34	54	46
Aspect (degrees)	90	45	112	300	288	326	312	292	65	310	210	170	15	248	145	300
Tree (spp.)	RO	RO	RO	WOCO	WO	RO	CO	WOSO	WO	RO	WO	WO	CO	RO	RO	CO
Timber type	Sap	Sap	SmP	SmS	SmP	SmS	MxS	SmP	SmS	SmS	SmP	MaS	SmS	MxS	MxS	MeS
Silviculture activity	—	—	—	—	TSI	TSI	—	TSI	TSI	TSI	TSI	—	—	TSI	TSI	TSI
Age class	E	E	E	U	E	E	U	E	E	E	E	E	E	U	U	U
Soil texture	Ls	L-T1	T1	V	L-T1	T1	Y1	Y1-L	T1-L	V	C1	Vc	V	Y1-L	V	Vc
Organic matter (%)	2.4	2.9	3.3	5.1	6.0	1.7	4.0	2.8	6.6	6.7	5.2	5.2	7.0	6.8	5.4	6.9
pH	4.4	4.4	4.2	4.4	4.2	4.2	3.8	4.4	4.3	3.5	4.2	4.0	3.7	3.8	4.1	3.8
B (ppm)	.06	.01	.03	.02	.03	.03	0	0	.03	.11	.06	.08	0	0	0	.02
Si (ppm)	12.5	10.3	0	0	0	0	0	0	0	0	0	0	0	0	13.6	17.2
Hg (ppm)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.2	0
Zn (ppm)	.6	0	0	.5	.5	.5	.3	.2	1.7	.7	.4	.3	1.2	.6	.9	1.3
P (ppm)	55.0	.5	3.0	3.4	4.5	4.5	4.5	3.1	6.0	8.9	3.1	3.2	6.4	4.8	10.0	12.2
Fe (ppm)	10.6	9.6	2.6	2.9	4.6	4.6	3.1	2.5	5.3	4.0	2.1	62.5	6.5	6.6	12.8	24.0
Cu (ppm)	65	45	44	40	53	53	59	13	65	33	22	9	26	38	66	52
Mn (ppm)	287	3	67	126	112	112	38	74	163	18	113	76	65	105	175	87
Mg (ppm)	135	5	16	34	22	22	21	28	90	24	25	25	34	23	40	46
Na (ppm)	88	62	10	14	16	16	7	9	27	11	8	7	17	8	13	18
Co (ppm)	47.0	1.0	9.0	0	0	0	1.0	0	0	0	0	1.0	0	0	28.0	43.0
Al (ppm)	9	0	6	10	9	9	5	6	12	7	10	11	17	12	15	31
Ni (ppm)	1.3	.3	0	.1	.1	.1	0	.1	.2	0	0	0	0	0	.3	.2
Ca (ppm)	516	411	100	395	194	194	129	228	731	150	175	197	142	349	233	246
Cr (ppm)	.2	.2	0	0	0	0	0	0	0	0	0	0	0	0	.2	.2
K (ppm)	132	36	62	120	95	52	67	93	147	88	99	72	151	77	137	139
Ti (ppm)	5.2	5.3	0	0	0	0	0	0	0	0	0	0	0	0	4.9	5.2
Pb (ppm)	9.3	8.2	0	.8	1.5	0	.6	14	1.6	.9	0	.3	.7	1.4	8.9	10.7
S (%)	.14	.15	0	0	0	0	0	0	0	0	0	0	0	0	.06	.06
No_3–(ppm)	.5	.2	.6	1.4	.6	.3	1.4	.9	4.0	1.8	3.1	.9	.8	1.8	.9	.4
Saturation (%)	41	50	86	98	110	122	123	86	127	33	118	122	118	135	119	141
−⅓ bars (%)	13	19	36	41	39	25	25	37	44	25	41	42	38	38	37	33
−3 bars (%)	7	12	12	20	16	9	13	12	24	18	24	18	24	17	22	24
−15 bars (%)	6	11	11	11	16	8	13	12	11	12	18	18	16	15	20	13
−⅓ & −15 (PAM) (%)	7	8	25	30	23	17	12	25	33	13	23	24	22	23	17	20
Cond. (1:2 soil:-water) (mmhos/cm)	.10	.04	.14	.16	.19	.11	.18	.13	.21	.43	.18	.19	.35	.24	.27	.31
Base exchangeable cap. (me/100 g)	4.40	2.45	.83	2.61	1.46	1.35	1.01	1.65	4.88	1.19	1.36	1.40	1.44	2.17	1.90	2.04

Sites are coded by areas and site numbers. Some site numbers are omitted. SM = surface mine, GR = Green Ridge State Forest, SR = Savage River State Forest. RO, WO, CO, SO = red, white, chestnut, scarlet oaks. Sap, SmP, MeP, SmS, Mes, MaS, MxS: saplings, Sm = small, Me = medium, Ma = mature, Mx = mixed, P = poles, S = sawtimber. E even-aged, U = uneven-aged, TSI = Timber Stand Improvement. L, Ls, T1, Y1, C1, V, Vc = loam, loamy sand, silt loam, sandy loam, clay loam, variable, variable clays. PAM = plant available moisture. Cond. = conductivity.

Table 3—*Characteristics for pine forests on surface mine sites and two state forests in Western Maryland*

	SMC	GRC		SRC					
Site characteristics	1	1	2	3	1	2	4	5	6
Elevation (m)	482	311	378	230	415	415	745	762	777
Slope (%)	5	2	1	1	5	5	5	6	5
Basal area (m²/ha)	6	29	43	56	40	51	40	51	29
Aspect (degrees)	90	112	270	156	180	290	19	341	334
Tree (spp.)	WRPR	WP	VPTP	WPVP	WP	RP	RP	WPRP	WPNS
Timber type	Sap	SmP	MeS	MaS	SmS	MeP	SmP	SmS	MeP
Silviculture activity	—	—	—	—	—	—	—	Thin	—
Age class	E	E	E	E	E	E	E	E	E
Soil texture	L	T1	T1	T1	L	L	T1	T1	T1
Organic matter (%)	3.5	2.4	2.3	2.4	3.6	3.1	3.8	3.6	3.2
pH	4.3	4.4	4.4	4.6	7.5	4.3	4.6	4.3	5.5
B (ppm)	.25	.17	.47	.55	1.11	.34	.46	.46	.96
Si (ppm)	30.7	12.2	21.2	20.9	29.0	84.2	42.0	17.9	48.3
Hg (ppm)	0	0	0	0	0	0	0	0	0
Zn (ppm)	2.9	2.3	2.9	2.6	4.2	3.9	9.3	4.0	1.9
P (ppm)	3.4	7.3	6.7	3.2	12.0	8.3	10.8	14.8	4.7
Fe (ppm)	153	273	122	114	80.8	181	161	233	202
Cu (ppm)	5	2	3	3	3	4	2	2	3
Mn (ppm)	16	103	234	215	176	178	250	395	182
Mg (ppm)	170	10	147	141	571	16	15	18	46
Na (ppm)	6	4	10	10	11	6	7	6	17
Co (ppm)	.6	.4	.5	.5	3.1	1.5	1.1	.9	1.2
Al (ppm)	186	491	573	528	490	873	1217	925	570
Ni (ppm)	.8	.4	2.2	2.0	1.7	.6	1.3	.7	.7
Ca (ppm)	286	45	360	327	4762	55	171	103	1636
Cr (ppm)	0	0	0	0	0	0	0	0	0
K (ppm)	63	45	82	77	156	67	68	117	99
Ti (ppm)	0	0	0	0	0	0	0	0	0
Pb (ppm)	4	1.0	1.1	.8	5.0	3.1	.3	.5	2.7
S (%)	.25	0	0	.01	0	0	.01	.01	.01
No_3- (ppm)	.5	.4	.5	.5	1.3	.5	.6	.5	.5
Saturation (%)	38	?	?	?	?	?	?	?	?
−1/3 bars (%)	15	30	24	31	?	27	24	23	28
−3 bars (%)	11	?	?	?	?	?	?	?	?
−15 bars (%)	7	12	9	16	?	12	16	13	13
−1/3 & −15 (PAM) (%)	8	18	15	15	?	15	8	15	15
Cond. (1:2 soil: water) (mmhos/cm)	.09	.09	.08	.09	.24	.11	.11	.29	.15
Base exchangeable cap. (me/100 g)	3.00	.56	3.25	3.03	28.9	.57	1.17	.98	8.86

Sites are coded by areas and site numbers. Some site numbers are omitted. SM = surface mine, GR = Green Ridge State Forest, SR = Savage River State Forest. WP, RP, VP, TP = white, red, Virginia, table-mountain pines. NS = Norway spruce. Sap, SmP, MeP, SmS, Mes, MaS, MxS: saplings, Sm = small, Me = medium, Ma = mature, Mx = mixed, P = poles, S = sawtimber. E = even-aged, U = uneven-aged. TSI = Timber Stand Improvements. L, T1 = loam, silt loam. PAM = plant available moisture. Cond. = conductivity.

References

1. Allen, E.B.; Allen, M.F. 1984. The physiologial ecology of mycorrhizae: implications for succession. Mycology Society of America Newsletter 35:17.
2. Allen, M.F.; Hipps, L.E. 1984. Comparative microclimates of some mycorrhizal fungi: requirements for long-range dispersal of spores. Mycology Society of America Newsletter 35:35.
3. Allison, L.E. 1965. Organic carbon. In: Black, C.A., et al., eds. Methods of soil analysis, part 1. Madison, WI: American Society of Agronomy.
4. Arnolds, E. 1981. Ecology and coenology of macrofungi in grasslands and moist heathlands in Drenthe, the Netherlands. 1. introduction and synecology. Bibliotheca Mycologica 83:1-407.
5. Beckjord, P.R.; McIntosh, M.S. 1984a. Growth and fungal retention by field-planted *Quercus rubra* seedlings inoculated with several ectomycorrhizal fungi. Bulletin of the Torrey Botanical Club 110:353-359.
6. Beckjord, P.R.; McIntosh, M.S. 1984b. Growth and fungal persistence by *Quercus rubra* inoculated with ectomycorrhizal fungi and planted on a clearcutting and strip mine. Canadian Journal of Botany 62:1571-1574.
7. Bills, G.F.; Holtzman, G.I.; Miller, O.K., Jr. 1986. Comparison of ectomycorrhizal-basidiomycete communities in red spruce versus northern hardwood forests of West Virginia. Canadian Journal of Botany 74:760-768.
8. Bower, C.A.; Wilcox, I.U. 1965. Soluble salts. In: Black, C.A., et al., eds. Methods of soil analysis, part 1. Madison, WI: American Society of Agronomy.
9. Bremner, J.M. 1965. Nitrogen availability indexes. In: Black, C.A., et al., eds. Methods of soil analysis, part 1. Madison, WI: American Society of Agronomy.
10. Bremner, J.M.; Tabatabai, M.A. 1971. Use of automated combustion techniques for total carbon, total nitrogen, and total sulfur analysis of soils. In: Walsh, L.M. ed. Instrumental methods for analysis of soils and plant tissue. Madison, WI: Soil Science Society of America: 2-14.
11. Danielson, R.M. 1984. Ectomycorrhizal associations in jack pine stands in northeastern Alberta. Canadian Journal of Botany 62:932-939.
12. Day, R. 1965. Particle fractionation and particle-size analysis. In: Black, C.A., et. al., eds. Methods of soil analysis, part 1. Madison, WI: American Society of Agronomy.
13. Flannery, R.L.; Markus, D.K. 1971. Determination of phosphorus, potassium, calcium, and magnesium in North Carolina, ammonium acetate and Bray P, soil extracts by autoanalyzer. In: Walsh, L.M., ed. Instrumental methods for analysis of soils and plant tissue. Madison, WI: Soil Science Society of America: 97-112.
14. Fogel, R. 1976. Ecological studies of hypogeous fungi. 2. sporocarp phenology in a western Oregon Douglas-Fir stand. Canadian journal of Botany 54:1152-1162.
15. Gardner, J.H.; Malajczuk, J. 1988. Recolonisation of rehabilitated bauxite mine sites in Western Australia by mycorrhizal fungi. Forest Ecology and Management 24:27-42.

16. Grossnickle, S.C.; Reid, C.P.P. 1982. The use of ectomycorrhizal conifer seedlings in the revegetation of a high-elevation mine site. Canadian Journal of Forest Research 12:354-361.
17. Hacskaylo, E.; Tompkins, C.M. 1973. World literature on mycorrhizae. Contrib. Reed Herbarium 22. Baltimore, MD: Paul M. Harrod Co. 142 p.
18. Lange, M. 1948. The agarics of Maglemose: a study in the ecology of the agarics. Dansk Botanisk Arkiv 13:1-141.
19. Lange, M. 1978. Fungus flora in August: ten years observations in a Danish beech wood district. Botanisk Tidsskrift 73:21-54.
20. LaRue, LI. 1971. A sample of the seasonal occurrence of higher fungi in Kalkaska County, Michigan. Michigan Botanist 10:125136.
21. Last, F.T.; Mason, P.A.; Smith, R.; Pelham, J.; Bhoja-Shetty, K.A.; Mahmood Hussain, A.M. 1981. Factors affecting the pro duction of fruitbodies of Amanita muscaria in plantations of Pinus petula. Proceedings of the Indian Academy of Sciences (Plant Sciences) 90:91-98.
22. Mason, P.A.; Last, F.T.; Pelham, J.; Ingleby, K. 1982. Ecology of some fungi associated with an aging stand of birches (Betula *pendula and* B. pubescens). Forest Ecology and Management 4:19-39.
23. Menge, J.A.; Grande, L.F. 1978. Effect of fertilization on production of epigeous basidiocarps by mycorrhizal fungi in loblolly pine plantations. Canadian Journal of Botany 56:2357-2362.
24. Molina, R.; Trappe, J.M. 1984. The mycorrhizal contribution of specific and nonspecific plantfungus associations to forest community dynamics. Mycological Society of America Newsletter 35:35.
25. Peech, M. 1965. Hydrogen-ion activity. In: Black, C.A., et al., eds. Methods of soil analysis, part 1. Madison, WI: American Society of Agronomy.
26. Richards, L.A. 1965. Physical condition of water in soil. In: Black, C.A., et al., eds. Methods of soil analysis, part 1. Madison, WI: American Society of Agronomy.
27. Schramm, J.R. 1966. Plant colonization studies on black wastes from anthracite mining in Pennsylvania. Transactions of the American Philosophical Society 56: part 1. 194 pp.
28. Smarda, F. 1963. Prispevek o vzajemnem vztahu hub a makroklimatu v roce 1962. Ceska Mykologie 17:141-148.
29. Trappe J.M. 1989. Personal communication.
30. Wilkins, W.H.; Harris, G.C.M. 1946. The ecology of higher fungi: 5. an investigation into the influence of rainfall and temperature on the seasonal production of fungi in a beechwood and a pinewood. Annals of Applied Biology 33:179-188.

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Pregermination Treatment and Stratification of Silverberry Seed

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Cold stratification treatments for optimal germination of silverberry (Elaeagnus commutata L.) were found to be 30 to 90 days at 4 °C. Water soaking in place of the cold stratification period was the least effective of the treatments applied. Tree Planters' Notes (41):24-25, 1990.

Silverberry (*Elaeagnus commutata* L.) is a native, stoloniferous, thicket-forming shrub useful in reclamation of strip mined lands in the Western United States and Canada.

Successful spring germination of silverberry seed can be accomplished by late fall planting, but situations occur in which stratified seed is required for spring planting. Recommended treatments for germination range from 10 to 90 days of cold stratification (3, 4), endocarp removal (2), and a 2-day water soak to remove a germination inhibitor (1). This study was conducted to determine specific seed treatments that would give optimum germination for spring planting.

Materials and Methods

Fruits of silverberry were collected in September 1985 from 5 plants of accession ND628 at the SCS Bismarck Plant Materials Center evaluation planting at McKenzie, ND. The fruits were cleaned by wet maceration and the seeds allowed to air dry. They were then stored at 4 °C until removed in October 1985 for use in this study.

The seeds were counted into 28 lots of 100 seeds each to be used in seven treatments, each of which was replicated four times. A cutting test of an additional 400 seeds revealed 97.25% filled seeds.

For three of the treatments, seeds were stratified in damp peatmoss in polyethylene bags at 4 °C for 30, 60, or 90 days. In three other treatments, seeds were soaked in water at room temperature for 2, 4, or 7 days, and the water was changed daily. The seeds were then placed in damp polyethylene bags. The seeds that were soaked in water for 2 days were then stratified at 4 °C for 30 days after soaking. Seeds in the seventh treatment, the control, were placed in peatmoss in polyethylene bags with no treatment.

At the end of each treatment period, the corresponding seed lots were allowed to germinate at room temperature, which ranged from approximately 20 to 30 °C. Germination counts were made weekly for a 4-week period.

Results and Discussion

All treatments resulted in seed germination of 73% or better, but speed of germination varied widely between treatments (table 1).

The control treatment resulted in zero germination the first week and over 88% the second week, with germination continuing into the third and fourth weeks. The water soaking treatments resulted in decreased cumulative germination rate (82 and 73%) at 4 weeks. Seeds that were soaked in water for 2 days and then stratified for 30 days showed 78% germination in the

Table 1—*Percent germination of silverberry seed over 28-day period*

Treatment	Weekly germination (%)				Cumulative total (%)
	Week 1	Week 2	Week 3	Week 4	
Stratification at 4 °C					
30 days	87.50	4.75	1.50	0.00	93.75
60 days	96.25	0.25	0.00	0.00	96.50
90 days	95.00	0.50	0.00	0.00	95.50
Water soak (2 days) + stratification (4 °C) (30 days)	78.25	10.25	0.75	1.00	90.25
Water soak (room temp.)					
4 days	4.75	57.25	16.0	4.25	82.25
7 days	2.00	41.50	20.50	9.50	73.50
Control	0.0	88.25	6.0	0.5	94.75

first week with almost no germination in the second through fourth weeks.

The cold stratification treatments gave excellent first week germination of 87% or greater and minimal second through fourth week germination. The 60- and 90-day cold treatments were superior to other treatments in total germination percentage (95 and 96%) and in speed of germination. There were no elongated radicals in storage in any of the treatments.

No evidence of a germination inhibitor was found within this North Dakota silverberry seed source. Water soaking is not recommended as an aid to germination. When planting silverberry in the spring, cold stratification for at least 30 days and up to 90 days may be used to obtain quick initial germination with optimal germination percentages.

Literature Cited

1. Fung, M.Y.P. 1984. Silverberry seed pretreatment and germination techniques. Tree Planters' Notes 35(3):32-33.
2. Hartmann, H.T.; Kester, D.E. 1975. Plant propagation principles and practices, 3rd ed. Englewood Cliffs, NJ: Prentice-Hall. 595 p.
3. Olson, D.F. 1974. *Elaeagnus L.* In: Schopmeyer, C.S., tech. coord. Seeds of woody plants in the United States. Agric. Handbk. 450. Washington, DC: United States Department of Agriculture: 376379.
4. Vories, K.C. 1981. Growing Colorado plants from seed: a state of the art. Gen. Tech. Rep. INT-103. Ogden, UT: USDA Forest Service. 25 p.

New Techniques for Tree Shaking in Older Seed Orchards

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Several new techniques were developed to shake large trees in older seed orchards without damaging their bark. The techniques worked equally as well as conventional shaking but were slower and could be expensive. Tree Planters' Notes 41(1):26-28; 1990.

Many acres of seed orchards in the Southeastern United States were planted in the late 1950's and early 1960's. The trees remaining after thinning and rogueing are 20+ years old and as large as 16 to 20 inches D13H. Although new, second-generation seed orchards are now coming to maturity, the older orchards are still producing the bulk of the seed used in the Southeast.

The process of collecting cones and seeds in older seed orchards is difficult because of the large size, both in height and DBH, of the trees. In addition, grafted seed orchard trees tend to have thinner bark than seedling-grown trees. The seed orchards have been thinned and rogued until there are only a select few trees remaining per acre. Trees have been heavily fertilized to enhance flowering. Such older, larger orchard trees generally produce large quantities of cones and seeds and their health and well-being must be protected.

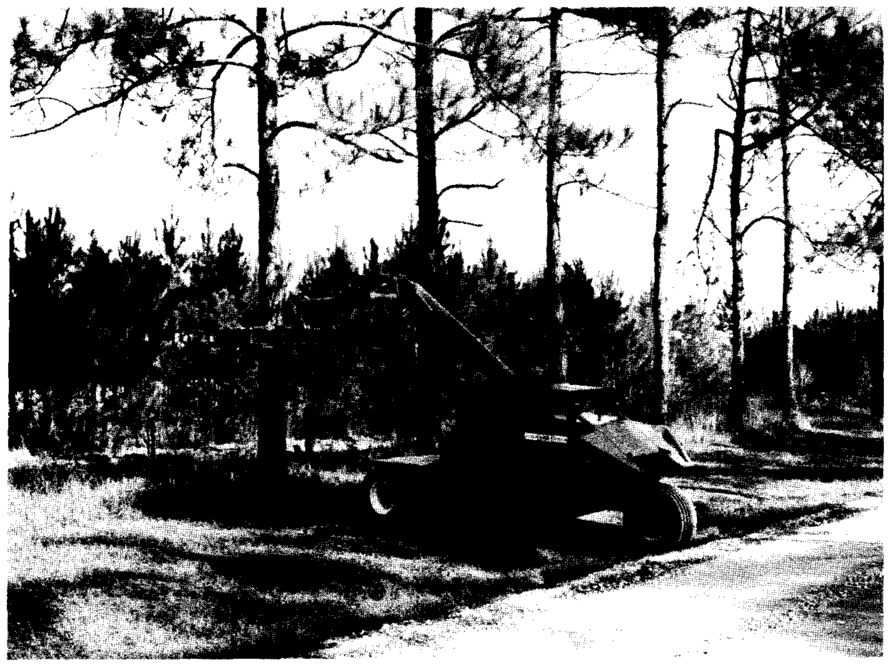

Figure 1—*Conventional tree shaking operation.*

Traditionally, commercial pecan shakers have been used to shake trees in seed orchards (fig. 1). Mechanical tree shakers do a satisfactory job of getting both cones and seed from the tree crown to the ground for most species and for younger, smaller-diameter trees.

However, for larger trees, the tree shakers apply more pressure to the trunks of the trees, which, in many cases, results in unacceptable damage to the bark. If the shaker operator does not position the gripping pads correctly, the shaking action will rub the bark and cause a wound on one or both sides of the tree trunk. These wounds will bleed resin and thus attract bark beetles and can also serve as an entry point for the spores of pitch canker and other diseases.

In an attempt to alleviate problems relating to bark damage from shaking seed orchard trees, the USDA Forest Service, region *8,* in cooperation with the Missoula Technology and Development Center, Missoula, MT, has evaluated several new techniques and pieces of equipment at the Forest Service

Francis Marion Seed Orchard near Charleston, SC. The orchard produces loblolly (*Pinus taeda* L.), longleaf (*P. palustris* Mill.) and shortleaf (*P. echinata* Mill.) seed for the national forests in North Carolina, South Carolina, and Georgia. Sixty-eight of the orchard's 138 acres are planted in loblolly pine. To date, 75% of the seed crops harvested has been loblolly pine. Seeds are mainly collected in nets laid under the trees.

Tree Shaker-Bolt System

Several types of bolts have been installed in the tree itself to eliminate the direct contact between the tree shaker pads and the bark of the tree. The bolts are of two basic types: threaded rod and lag screw.

The threaded rod type bolt was first used in tests to evaluate the initial idea. Although the concept was established as potentially useful, it was immediately obvious that there were several problems to overcome. A threaded rod placed in a hole that has been drilled completely through the heart of a tree does create certain mechanical and physical problems for the tree. Testing established that the conventional pecan-type tree shaker could transfer enough energy to the tree to dislodge both cones and seeds, and the tree did not appear to be damaged. However, this type of bolt has several other problems:

Hole through the tree. The diameter of the hole must be as small as possible to minimize the structural weakening of the trunk. On the other hand, the rod diameter needs to be as large as possible to prevent bending. After many size comparisons, it was found that a 1½ inch-diameter threaded shaft was the best compromise.

Thrust plates. If the compression nut, which holds the thrust plates tight to the sides of the tree, is not released each year after shaking, the tree tends to overgrow the thrust plate. It does not take long until the shake points can no longer be located and used.

Acorn nuts. The rod ends extending out on each side of the tree must be able to meet the shaker head in order to transmit the energy from the shaker to the tree. A conventional hex head nut (domed on the outboard end) was found to provide a good interface between the threaded shaft and shaker head.

Bolt length (threaded entire length). The portion of the bolt extending beyond the tree on either side bends from the shaking action. The greater the extension, the larger the moment arm, and the more chance there is of bending the rod. In an attempt to correct this problem, the bolts were cut to length for each tree. This did not allow for future growth and the threaded section must be replaced periodically.

Shaker-head adapter plates. The tree shaker as supplied for conventional tree shaking has resilient pads designed to grip the tree trunk. The pads do not interface well with the bolt heads, therefore a dimpled metal plate was substituted for the pads. The domed bolt heads fit into one of the dimples, which serve as receptors (fig. 2).

The offset rows of dimples help insure alignment when the shaker head is closed and make it possible to accommodate some misalignment or tilt. To date the plates have worked well in transferring the shaker's energy to the tree.

Clamping of the shaker head. Visual alignment of the bolts and shaker head prior to clamping is extremely critical and at the same time difficult to

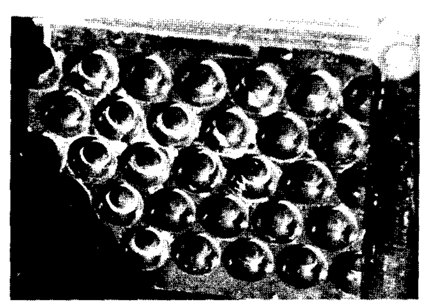

Figure 2—*Receptor plate (attached to shaker head).*

accomplish. All the problems associated with rapid clamping have not been solved. At present attachment is quite slow, too long for a production operation, and cannot be done by the operator without a second person.

Lag Screws

Using the lag screws, which is presently under evaluation, appears to eliminate many of the problems associated with the threaded rods. A basic lag screw with a domed hex nut welded to the top is used (fig. 3).

A shallow hole of matching diameter to the lag screw is drilled into each side of the tree and the lag screw inserted (fig. 4). Each year after shaking the lag screw is backed out enough to permit room for growth. The following concerns have been eliminated:

1. Structural damage to the tree created by drilling holes completely through the tree.
2. Bending of rod extensions.
3. Thrust plate overgrowth.
4. The jam nut used to hold the outboard nut working loose.

Overall, the system is working quite well and shows promise of being a workable system. Technology development by the Forest Service is on hold until a definite need is determined.

Note added in proof: Hurricane Hugo struck the Francis Marion Seed Orchard September 21, 1989. Many orchard trees were broken by its winds. The evidence is inconclusive that the bolts caused trees to break: some trees containing bolts broke, others did not. Some with bolts broke above the bolt.

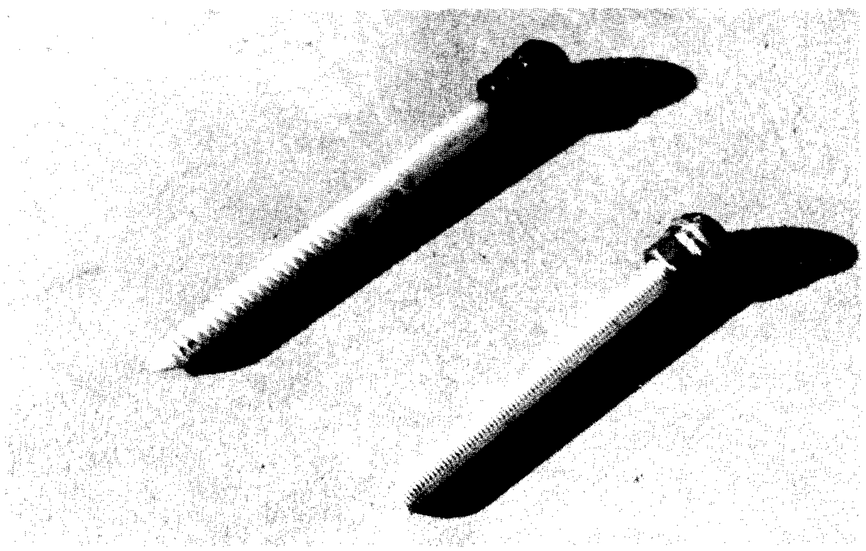

Figure 3—*Lag screw with domed hex nut head.*

Figure 4—*Lag screw installed in tree.*

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Comparison of Disease Management Strategies for Control of Soil-Borne Pathogens in a Forest Tree Nursery

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In a Wisconsin forest tree nursery, pre-emergence mortality of white spruce (Picea glauca (Moench) Voss) was greatest in nontreated plots and least in plots treated with dazomet. Nontreated plots had the most postemergence damping off, and plots treated with silica sand had the least. Seedling mortality was greatest during the first growing season (28% in dazomet-treated plots, 61% in nontreated plots). However, seedling losses were less than 8% in all treatments during the second and third growing seasons. After the first growing season, the incidence of stunting was greatest in plots treated with dazomet and least in plots where seeds were covered with sand. Most of the stunted seedlings recovered during the second and third years of growth. At the end of both the first and third growing seasons, plots treated with dazomet had significantly more seedlings than any other treatment. At the end of the rotation, all treatments had similar numbers of cull seedlings. Tree Planters' Notes 41(1) :29-33; 1990.

Paper no. 17,379 of the contribution series of the Minnesota Agricultural Experiment Station, St. Paul, MN. The authors thank John Borkenhagen, manager of the Hayward State Nursery, and Robert Collet and Debra Neilson for their help.

White spruce (*Picea glauca* (Moench) Voss) is an important tree species in Minnesota, Wisconsin, and Michigan forest tree nurseries and accounts for 15% of bareroot seedling production. During the 3-year rotation, production of white spruce seedlings is often reduced due to pre-emergence and postemergence damping-off (1) and root rot caused by *Cylindrocladium* spp. (6).

In the Lake States, nurseries routinely fumigate with methyl bromide or dazomet to reduce populations of soil-borne fungi. However, fumigation also reduces populations of beneficial soil organisms such as mycorrhizal fungi (10). Reduced or delayed mycorrhizal formation may result in stunted, nutrient-deficient seedlings and eventual seedling mortality (3, 7). Roots of stunted white spruce may become mycorrhizal in subsequent years but still do not attain the size of nonstunted white spruce and may be culled (2). Thus, some of the benefits of disease control from soil fumigation may be lost due to detrimental effects on mycorrhizal development.

Alternatives to fumigation, such as chemical seed treatments (5), fungicide drenches (8), and soil solarization (4) have been tested, but have not proved as effective as fumigation. These practices may, however, produce satisfactory disease control while minimizing losses from stunted seedlings.

In this study, we evaluated the relative effectiveness of several disease management strategies-fumigation, seed treatment, soil drenches, and cultural treatment-on growth, incidence of stunting, and survival of white spruce seedlings during a 3-year rotation.

Methods

The experiment was conducted at the Hayward State Nursery, located in Hayward, WI. In early May 1985, the experimental area was sown with a cover crop of buckwheat (*Fagopyrum esculentum* Moench) that was turned under in early July. And in August both peat (800 pounds per acre) and fertilizer (10:20:10, 250 pounds per acre) were incorporated into the soil.

Four chemical treatments were applied to 4 x 40 ft plots:

1. Dazomet, a fumigant, applied at a rate of 125 pounds active ingredient (ai) per acre as a top dressing on August 1, 1985, and then worked into the soil to a depth of 12 inches. The soil was packed with a roller and irrigated with 1 inch of water.

2. Thiram applied as a seed coat with 1.5 ounces ai and 16 ounces of spreader-sticker per pound of white spruce seed.

3. Captan applied as a soil drench at a rate of 5 pounds ai per acre on April 11, 1986, after the soil was free of frost.

4. Captan applied as a soil drench on plots that had been sown with thiram-treated seed.

Nontreated plots served as controls. A completely randomized experimental design was used with three replications of each treatment.

On October 12, 1985, two 4-by 500-foot seed beds were formed, lined with bedboards, and all the plots were sown with seed. The cultural treatment, of No. 40 washed silica sand, was placed directly over hand-sown seed in 2- by 0.5-inch furrows. After the seeds were covered with sand, the plots were packed with a roller to simulate machine sowing. The remaining plots, which had been chemically treated, were then mechanically sown with white spruce seed at a rate of 0.24 ounce per 10.7 square feet. After sowing, seed beds were covered with 50% polypropylene shade cloth and left until spring. Prior to germination, five 4-foot-square randomly located permanent assessment subplots were established in each treated plot to evaluate: pre-emergence mortality, postemergence damping off, incidence of stunting, and seedling stand densities. For convenience, results are presented as seedlings per square foot.

Throughout the experimental period, standard nursery practices were used to maintain seedling growth. This included overhead irrigation applied every other day at the rate of 0.5 inch per day when normal precipitation was inadequate. An N/P/K fertilizer was applied 3 to 4 times per year at 200 to 400 pounds per acre, depending upon soil fertility requirements within the plots.

With each ounce of white spruce seed containing 791 seeds (190 seeds per square foot), and a germination rate of 85%, 161 seedlings were expected to emerge per square foot. Differences between the expected number of seedlings and the actual number of seedlings that emerged were attributed to pre-emergence mortality. Seedlings that had rapidly decaying stems or water-soaked lesions near the ground line were classified as having postemergence damping-off.

During the first growing season seedling stand densities were evaluated on May 18, June 18, July 22, and September 23, 1986, by counting all the living white spruce seedlings within the assessment subplots. The incidence of stunting was determined on September 23, 1986 by counting seedlings that had purple foliage and small stature (2).

First-year seedling yields were calculated by subtracting the number of stunted seedlings in each subplot from the total number of seedlings per subplot. At the end of the third growing season, on September 28, 1988, all seedlings within the assessment subplots were removed from the soil and counted, and their heights were measured to the nearest inch. Final yield of third-year seedlings per treatment was determined by subtracting the number of cull seedlings from the total number of seedlings. Cull seedlings were all seedlings less than 4 inches or greater than 18 inches in height.

Data were analyzed by an analysis of variance. Differences among means were determined with the Student-Newman-Keuls' test. Data presented as percentages are arcsine transformation of means.

Results and Discussion

No single management strategy was found to minimize stunting and provide satisfactory disease control in the first year. Pre-emergence mortality was greatest in nontreated plots (86 seeds per square foot) and least in dazomet-treated plots (72 seeds per square foot) (table 1). Although pre-emergence mortality was lower with dazomet than with captan, thiram, or the captan-thiram treatments, differences among chemical treatments were not significant (table 1). Nontreated plots had significantly more postemergence damping-off (10 seedlings per square foot), whereas plots with silica sand had the least amount of postemergence damping-off (2 seedlings per square foot) when compared with fungicide treatments.

Stand densities of 1 + 0 seedlings were lowest when seeds were covered with silica sand or planted in nontreated soils. Poor initial stand densities in the silica sand plots were due to sand erosion that left seeds exposed on the soil surface rather than to disease. Silica sand may have benefits other than reducing disease. Tinus (9) found that covering seed of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) with sand instead of soil increased seedling size and stand densities. He attributed this improvement to reduced soil crusting and better water percolation. Germination might have been higher in the silicia sand treatment if the seeds had been sown with a machine drill rather than by hand.

Seedling stand densities declined throughout the first growing season regardless of treatment, with mortality ranging from 28% in the dazomet treatment to 61% in nontreated plots (fig. 1). By the end of the first growing season (September 1986), plots treated with dazomet had significantly higher 1 +0 seedling stand densities than any other treatment group (fig. 1), but almost half the seedlings were stunted (table 1).

Captan, thiram, and the combined captan-thiram treatments produced lower stand densities than dazomet and had almost as many stunted seedlings as the dazomet treatment. In contrast, while producing fewer seedlings, plots treated with silica sand had only 19% stunted seedlings (table 1). However, at the end of the first growing season, plots treated with dazomet, thiram, silica sand, or nontreated plots had similar numbers of healthy, non-stunted seedlings (table 1).

Stunted seedlings survived the rotation, and most eventually attained the height of non-stunted seedlings. These results do not support those of Croghan and LaMadeleine (2), who found that stunted white spruce in a northern Minnesota nursery survived the rotation but never recovered in height and thus were culled because they did

Table 1—*Response of white spruce to disease management strategies at Hayward State Nursery, Grant County, WI, in 1986 (first-year) seedlings and 1988 (second-year) seedlings*

	Pre-emergence mortality		Post-emergence damping-off		First year (1+0) Stand densities*	First year (1+0) Stunted seedlings		First year (1+0) Non-stunted seedlings	Third year (3+0) Stand densities*	Third year (3+0) Cull seedlings		Third year (3+0) Acceptable seedlings†
Treatment	No./ft²	(%)	No./ft²	(%)	No./ft²	No./ft²	(%)	No./ft²	No./ft²	No./ft²	(%)	No./ft²
Dazomet	72 a	46	4 ab	4	61 a	30 a	49 a	31 ab	57 a	5 a	8 a	52 a
Captan	80 abc	52	5 ab	8	46 bc	20 b	43 ab	26 b	44 b	5 a	12 a	39 b
Thiram	76 ab	49	8 c	10	47 b	17 b	32 abc	31 ab	43 bc	5 a	11 a	38 bc
Captan/Thiram	82 abc	53	6 a	8	45 bc	20 b	42 abc	25 b	43 bc	6 a	13 a	38 bc
Silica sand	83 bc	54	2 a	3	48 b	9 c	19 d	39 a	48 b	7 a	15 a	41 b
Nontreated	86 c	56	10 d	15	36 c	8 c	26 cd	28 b	36 c	4 a	11 a	32 c

*Stand densities were all seedings within the assement plots.
†Acceptable seedlings were seedlings greater than 4 inches and less than 18 inches.
Values are averages of 3 plots per treatment; values followed by the same letter within a column do not differ significantly at 0.05 according to the Student-Newman-Keuls' test.

not meet the minimum grading specifications.

After the third growing season, plots treated with dazomet had the highest seedling stand densities and, after grading, the greatest number of acceptable seedlings per plot (52 per square foot). Nontreated plots had the lowest number of acceptable seedlings per plot (32 per square foot). All other treatments produced between 41 and 38 acceptable seedlings per square foot. In all treatments, less than 8% of the seedlings died during the second and third growing seasons.

This study demonstrated that most seedling losses occurred in the first growing season. Fumigation with dazomet produced the greatest number of stunted 1 + 0 seedlings but ultimately had no effect on 3 + 0 seedling height. Silica sand and thiram may be alternatives that can be used in some nurseries with success, and these practices could be implemented to produce larger number of non-stunted white spruce seedlings.

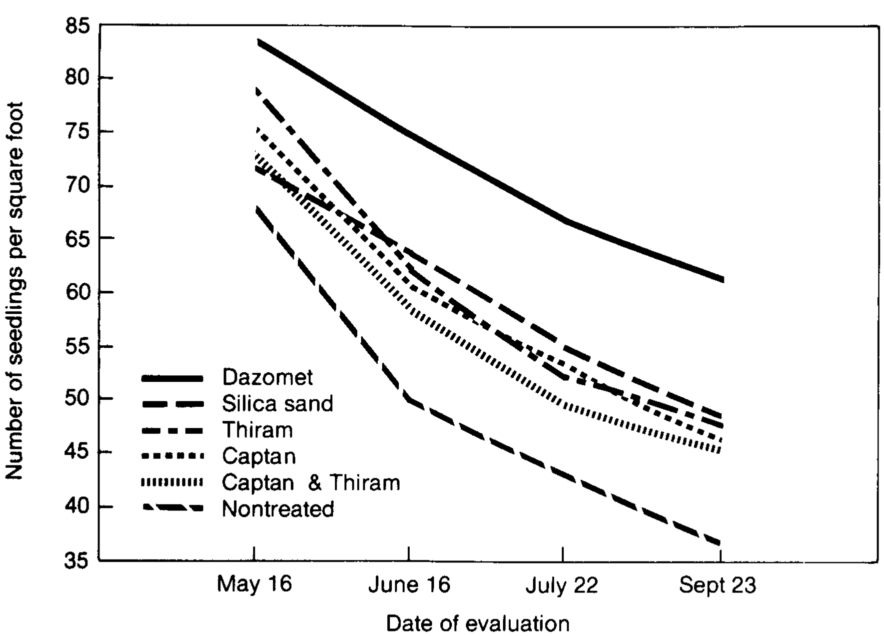

Figure 1—*Decline of seedling stand densities in all treatments at the Hayward State Nursery, Grant County, WI. Values represent the average of five 4-square-foot permanent assessment subplots collected over the first growing season in 1986.*

Literature Cited

1. Aldhous, J.R. 1972. Nursery practice. For. Comm. Bull. 43. London: Her Majesty's Stationery Office. 184 p.
2. Croghan, C.F.; LaMadeleine, L.A. 1982. The impact of stunting of white spruce at Eveleth nursery. Tree Planters' Notes 33:19-22.
3. Henderson, G.S.; Stone, E.L., Jr. 1970. Interactions of phosphorus availability, mycorrhizae, and soil fumigation on coniferous seedlings. Soil Science Society of America Proceedings 34:314-318.
4. Hildebrand, D.M.; Dinkel, G.B. 1988. Evaluation of methyl bromide, Basamid® granular, and solar heating for pre-plant pest control for fall-sown eastern redcedar at Bessey Nursery. Tech. Rep. R2-41. Lakewood, CO: USDA Forest Service, Rocky Mountain Region, Timber, Forest Pest, and Cooperative Forestry Management. 13 p.
5. James, R.L. 1984. Evaluation of fungicides to control root diseases at the Champion Timberlands Nursery, Plains, Montana. Rep. 84-9. Missoula, MT: USDA Forest Service, Northern Region, Forest Pest Management. 19 p.
6. Menge, J.A.; French, D.W. 1976. Determining inoculum potential of *Cylindrocladium flor idanum* in cropped and chemically treated soils by a quantitative assay. Phytopathology 66:862-867.
7. McComb, A.L. 1938. Relation between mycorrhizae and the development and nutrient absorption of pine seedlings in a prairie nursery. Journal of Forestry 36:11481153.
8. Smith, R.S., Jr.; Bega, R.V. 1966. Root disease control by fumigation in forest nurseries. Plant Disease Reporter 50:245-248.

9. Tinus, R.W. 1987. Modification of seed covering material yields more and larger pine seedlings. Tree Planters' Notes 38:11-13.

10. Trappe, J.M.; Molina, R.; Castellano, M. 1984. Reactions of mycorrhizal fungi and mycorrhizae formation to pesticides. Annual Review of Phytopathology 22:331359.

Effects of Five Antitranspirants on White Spruce and White Pine Seedlings Subjected to Greenhouse Drought

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Five film-forming antitranspirants (Cloud Cover, X2-1337, Plantco, Vapor Gard, and Wilt Pruf) were applied to containerized white spruce (Picea glauca (Moench.) Voss) a. white pine (Pinus strobus L.) seedlings transplanted into pots in the greenhouse. After 28 days without water the survival, level of foliar damage, height growth, and biomass were recorded for each seedling. Although many of the differences were not statistically significant, seedlings treated with Wilt Pruf had the most favorable seedling characteristics: high survival rate, low levels of foliar damage (needle browning or tip death), and high biomass in combination with moderate height growth. Seedlings treated with Vapor Gard had a high survival rate but showed variation in accumulated biomass and height growth with high levels of foliar damage. Treatment with X2-1337 and Plantco resulted in greater height growth but low biomass (suggesting a poorer root/shoot ratio) and variable effects on survival and foliage. Treatment of white spruce or white pine seedlings treated with Cloud Cover was not effective, and *the seedlings responded in a similar fashion to those not treated.* Tree Planters' Notes 41(l):34-38* 199f)

Poor survival of conifer seedlings because of drought is a widespread impediment to successful regeneration efforts on certain forest sites in many areas. Antitranspirants might be useful in improving regeneration success through two mechanisms: the reduction of transpiration losses during the stressful period after outplanting and the extension of the spring planting season by pretreatment of seedlings to resist drought stress (6, 9). Ideally, treatment with an antitranspirant would increase the survival rate, prevent water loss by trees, and increase or allow seedling growth, although not necessarily in height.

Antitranspirants can be classified into those that either cause stomatal closure, form thin films, form thick films, or reflect light (7). The results of tests on the use of antitranspirants of these types have been inconsistent. Although research has shown positive results in some cases, certain antitranspirants have had toxic effects on different plant species under varying conditions (3). For these reasons, Simpson (9) suggested a screening process for antitranspirants to use on coniferous outplanting stock.

With respect to antitranspirants examined in this study, Simpson (9) did not recommend treatment of certain coniferous seedlings with Wilt Pruf and Vapor Gard, and concentrations of 1:10 and 1:20, respectively. These treatments increased seedling ability to withstand moisture stress but also had negative impacts on root growth capacity, storability, and field survival/growth of containerized white spruce (*Picea glauca* (Moench) Voss), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). An exception was noted with lodgepole pine (*Pinus contorta* Dougl. ex Loud.) seedlings which, when treated with Wilt Pruf, showed reduced moisture stress development without significantly reducing root growth capacity or storability. Similarly, Davies and Kozlowski (2) found that Wilt Pruf had favorable effects on transpiration and photosynthesis in white ash (*Fraxinus americana* L.) and red pine (*Pinus resinosa* Ait.) seedlings.

Odlum and Colombo (1,4-6) conducted a number of experiments on the use of antitranspirants on containerized black spruce (*Picea mariana* (Mill.) B.S.P.) seedlings. They found that X2-1337 was most effective in reducing water loss although Wilt Pruf, Vapor Gard, Plantco, and Cloud Cover were

Table 1—*Product formulation and supplier*

Antitranspirant	Type of compound	Supplier
Cloud Cover	Not available*	Adkar Inc., 1006 South Tenth Street McAllen, TX 78501
X2-1337	Polydimethyl–siloxane emulsion	Dow-Corning Canada, Inc. 6747 Campobella Road Mississauga, ON L5N 2M1
Plantco	Acrylic emulsion	Plant Products Co. Ltd. 314 Orenda Road Bramalea, ON L6T 1G1
Vapor Gard	Pinolene	Miller Chemical and Fertilizer Corp. Hammer, PA 17331
Wilt Pruf	Pinolene	Nursery Specialty Products Greenwich, CT 06830

*Supplier defunct or relocated.

also effective to a lesser extent. However, Wilt Pruf and X2-1337 were also associated with increased mortality (6) and Vapor Gard resulted in high incidence of needle browning. They suggested that X2-1337 might be useful for preventing desiccation over winter and that Plantco and Cloud Cover may be more suitable for reducing postplanting water loss.

The study reported on here expands on the work of Odlum and Colombo (4-6) and Colombo and Odlum (1) testing many of the same antitranspirants on white pine and white spruce seedlings in pots. We tested the effects of 5 film-forming antitranspirants (table 1) on the growth and survival of containerized white spruce and white pine (*Pinus strobus* L.) seedlings subjected to drought in the greenhouse.

Methods and Materials

Flats of white spruce seedlings and white pine tubelings were grown for 14 weeks under standard conditions in greenhouses at the Orono Forest Tree Nursery, Ontario Ministry of Natural Resources, and then placed in cold storage at -3 °C. After 4 months, the seedlings were removed from cold storage and transported to a greenhouse at the University of Guelph. Groups of 5 white pine or 4 white spruce seedlings were transplanted into pots containing equal portions of peat, vermiculite, and sand, and then watered generously.

Three replications of six antitranspirant treatments were applied in a randomized complete block experimental design for each tree species, with each pot being treated as an experimental unit. The treatments were applied by dipping the seedlings into a control (tap water) or 5% solutions of Vapor Gard, X2-1337, Plantco, Cloud Cover, or Wilt Pruf and tap water. The total heights and root collar diameters of the seedlings were recorded.

The white spruce seedlings were destructively sampled after 28 days, during which time they were not watered. The total height and root collar diameter of the seedlings were measured, the root systems were cleaned of soil, and wet and dry weights of the seedlings were recorded. Seedling survival and the presence of browned foliage, or tip death, on surviving seedlings was also recorded. The white pine seedlings were destructively sampled at 35 days and measurements similar to those made on white spruce were taken.

Analysis of variance was conducted using PCSAS (8) general linear models procedure. Height growth and biomass were used as dependent variables in the ANOVA and tree species, antitranspirant, and the tree species-antitranspirant interaction terms were used as independent variables. Duncan's multiple range test was used to detect differences among treatment means. A similar analysis was conducted for seedling survival and burned (desiccated) foliage using experimental unit means for ANOVA and individual seedling data for multiple range testing. Square root or arcsine transformations to the survival or foliar damage (needle browning or tip death) data did not result in any improvement in the analysis. A significance level of 0.10 was used in means separation ($p > 0.10$) because two of the treatment differences were significant at that level in the ANOVA. Rankings of variables were also used to illustrate trends in the results. Additional ANOVA were conducted using initial seedling height and percent height increase as dependent variables, but the information is redundant and not reported in this note.

Table 2—*The probability of significant differences from ANOVA in characteristics of white spruce and white pine seedlings due to anti-transpirant treatment*

Variable	White spruce (p > f)	White pine (p > f)
Height growth	0.6680	0.0685
Biomass	0.0850	0.3688
Survival	0.4562	1.0000
Browned foliage	0.0483	0.6254

Table 3—*Treatment means for white spruce and white pine seedlings treated with five antitranspirants*

Treatment	Height growth (cm)	Biomass (g)	Survival (%)	Browned foliage (%)
White spruce				
Control	1.6	0.40 a	66.7	54.5 bc
Cloud Cover	1.8	0.27 b	60.0	50.0 bc
X2-1337	1.6	0.21 b	86.7	76.9 a
Plantco	1.6	0.21 b	73.3	57.1 bc
Vapor Gard	1.2	0.20 b	93.3	60.0 ab
Wilt Pruf	1.2	0.23 b	100.0	40.0 c
White pine				
Control	1.6 a	1.40	100.0	50.0
Cloud Cover	1.7 a	1.39	100.0	58.3
X2-1337	2.9 b	1.14	100.0	25.0
Plantco	1.8 a	1.10	100.0	16.7
Vapor Gard	3.0 b	1.22	100.0	50.0
Wilt Pruf	2.1 ab	1.35	100.0	25.0

Means within columns for each species followed by the same letter do not differ significantly ($P < 0.1$).

Results and Discussion

Ideally, characteristics of antitranspirant-treated seedlings subjected to drought would include a high survival rate with minimal desiccation of foliage, combined with reasonable height and biomass growth, indicating more vigorous root growth.

ANOVA (table 2) and Duncan's multiple range test (table 3) resulted in significant differences among white spruce seedlings due to treatment effects in browned foliage ($p < .05$) and biomass ($p < .10$). The mean biomass of the control seedlings was significantly greater than for the treated seedlings (table 3). However, the untreated seedlings had one of the lowest survival rates (not significant) and a moderate level of foliage browning on surviving seedlings. White spruce seedlings treated with Wilt Pruf had the best survival rate and the lowest level of foliage browning (tables 3 and 4). Seedlings treated with Cloud Cover responded in a similar fashion to the control seedlings. For white pine seedlings, ANOVA found significant differences due to treatment effects in height growth only (table 2). Multiple range testing showed that the control seedlings and those treated with Cloud Cover and Plantco had significantly less height growth than seedlings treated with X2-1337 or Vapor Gard (table 3). There was 100% survival in white pine for all treatments and no significant differences due to treatment effects for the surviving seedlings with respect to foliage browning, although Plantco-treated seedlings showed the least browning (not significant).

Rankings (table 4) illustrate that seedlings from the control and Cloud Cover treatments were lowest in height growth and highest in biomass (suggesting a higher root biomass) but were also highest in number of seedlings with burned foliage. White pine seedlings treated with Wilt Pruf had moderate height growth and biomass combined with a lower level of foliage browning.

As indicated above, few significant differences attributable to treatment effects were found among tested seedlings in this study. Perhaps the most important differences were found in the low level of foliage browning among surviving white spruce seedlings treated with Wilt Pruf. This is significant, especially considering the 100% survival rate for the white spruce treated with this antitranspirant. Although differences among white pine seedlings for this variable were not significant, the ranking showed that seedlings treated with Wilt Pruf also had lower levels of foliage browning among surviving seedlings. Both species showed excellent survival when treated with this antitranspirant (table 4).

The control and Cloud Covertreated seedlings of both species ranked similarly in all tested variables. This presents an interpretative anomaly in some cases where it appears that the control seedlings actually performed better than would be expected. For example, control and Cloud Cover-treated white spruce seedlings had the highest height growth and biomass, a relatively low level of foliage browning, but the highest mortality rate. This can be explained by the death of less vigorous seedlings during the experiment, leaving thriftier seedlings with less foliar damage.

Overall, treatment of both white spruce and white pine seedlings with Wilt Pruf resulted in the most favorable seedling characteristics: high survival rate, low levels of foliar damage and higher biomass in combination with moderate height growth. Seedlings treated with Vapor Gard had a high survival rate but showed variation in biomass and height growth and high levels of foliage browning. Seedlings with X2-1337 and Plantco responded with greater height growth but low biomass (suggesting a poorer root/shoot ratio); inconsistent effects on survival and foliage were also noted. Treatment of white spruce or white pine seedlings treated with Cloud Cover was not effective.

Table 4—*Rankings for treatment means for height growth, biomass, survival, and burned foliage of white pine and white spruce seedlings treated with five antitranspirants*

	Height growth		Biomass		Survival		Browned foliage	
Treatment	Pine	Spruce	Pine	Spruce	Pine	Spruce	Pine	Spruce
Control	6	2	1	1	1	5	2	4
Cloud Cover	5	1	2	2	1	6	1	5
X2-1337	2	2	5	4	1	3	3	1
Plantco	4	2	6	4	1	4	4	3
Vapor Gard	1	3	4	5	1	2	2	2
Wilt Pruf	3	3	3	3	1	1	3	6

Rankings: 1 = highest, 6 = lowest.

Conclusions

The application of antitranspirants does show some benefit to white spruce and white pine seedlings with improved survival and vigor during a period of drought following planting. In this study, seedlings treated with Wilt Pruf showed the best results. Seedlings treated with Vapor Gard also responded positively relative to untreated seedlings and treatment with X2-1337 and Plantco had moderate but indistinct effects on seedling characteristics. The results of this experiment suggest that some of these antitranspirants, particularly Wilt Pruf, have potential for use on a practical basis and should be considered for operational use subject to additional testing under greenhouse and field conditions.

Literature Cited

1. Colombo, S.J.; Odium, K.D. 1987. Efficacy of six antitranspirants on black spruce container seedlings. New Forests 3:239-244.
2. Davies, W.J.; Kozlowski, T.T. 1974. Short- and Long-term effects of antitranspirants on water relations and photosynthesis of woody plants. Journal of the American Society of Horticultural Science 99:297-304.
3. Kozlowski, T.T. 1986. The impact of environmental pollution on shade trees. Journal of Arboriculture 12(2):29-37.
4. Odium, K.D.; Colombo, S.J. 1984. A comparison of three antitranspirants for reducing water loss in black spruce container seedlings. Nurs. Note 110. Maple, ON: Ontario Ministry of Natural Resources. 4 p.
5. Odium, K.D.; Colombo, S.J. 1986. Antitranspirants that reduce water loss from black spruce container seedlings. Nurs. Note 116. Maple, ON: Ontario Ministry of Natural Resources. 3 p.
6. Odium, K.D.; Colombo, S.J. 1987. The effect of three film-forming antitranspirants on moisture stress of outplanted black spruce seedlings. Tree Planters' Notes (38)4:23-26.
7. Rietveld, W.J.; Heidmann, L.J. 1969. Influence of antitranspirants on water use, growth characteristics, and relative drought resistance of ponderosa pine seedlings. Res. Note RM-151. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 6 p.
8. SAS Institute, Inc. 1985. SAS/STAT guide for personal computers, Version 6 ed. Cary, NC: SAS Institute, Inc. 378 p.
9. Simpson, D.G. 1984. Filmforming antitranspirants: their effects on root growth capacity, storability, moisture stress avoidance, and field performance of containerized conifer seedlings. Forestry Chronicle 60(6):335-339.

Dicloran Fungicide Causes Stem Injury to Container Spruce Seedlings

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Postsowing applications of the fungicide dicloran (Botran ®) caused stem injury to young blue spruce (Picea pungens Engelm.) seedlings in a Colorado forest nursery greenhouse. Initial symptoms for some of the affected seedlings included stunting, stem swelling, and twisting. Seedlings without conspicuous symptoms appeared to develop normally until later in the growing season, when they fell over or they became brittle and broke when handled during packing and shipping. Tree Planters' Notes 41(1):39-42; 1990.

The Colorado State Forest Service Nursery in Ft. Collins, CO, has grown conifer seedlings in its greenhouses for over 25 years. The nursery produces a wide variety of conifer seedlings in containers, but Colorado blue spruce (*Picea pungens* Engelm.) has continued to be in great demand. Two crops of 1 + 0 container seedlings are produced annually, but spruces are normally grown in the spring crop. Colorado blue spruce is sown in the spring, grows in the greenhouse through the summer, and then is hardened off and over-wintered in shadehouses for sale the following spring.

In the spring of 1985, nursery employees began to notice stunting and abnormal shoot twisting (fig. 1) of blue spruce seedlings a few weeks after the seedlings had begun shoot extension. The affected seedlings failed to develop normally and were soon overtopped by adjacent seedlings. Later in the growing season, other seedlings developed a stem swelling in the area of the hypocotyl above the cotyledon scar (fig. 2); others appeared to develop normal shoots but later fell over.

A closer examination of the lower stem of these seedlings revealed a swollen area in the same region of the stem; the part of the stem below the swelling was very constricted, however, creating a mechanical weakness (fig. 3). Apparently, this physically weakened lower stem was unable to support the heavier shoot, causing the seedling to fall over (fig. 4), or the stem would break at the constriction when the seedling was handled during grading and sorting. By the end of the 1985 growing season, 27% of the blue spruce crop had been damaged and had to be culled.

Figure 1—*Stunting and abnormal shoot twisting of blue spruce seedlings soon after shoot extension has begun.*

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After reviewing the cultural records for the damaged crop and considering the type and development of the stem injury symptoms, two different hypotheses were developed to account for the problem: the growing media could have been contaminated with some phytotoxic chemical, or the seedlings could have been damaged by fungicides applied to control damping-off.

Two different fungicides had been applied to the young spruce crop as postsowing treatments: captan (Captan®) and dicloran (Botran®). Although not specifically registered for control of damping-off, dicloran was applied in rotation with captan in an attempt to provide better fungal control.

Materials and Methods

In the fall of 1985, an operational experiment was designed to try to recreate the conditions that led to the stem swellings. A group of blue spruce seedlings were grown in Colorado Styroblocks, which are Styrofoam block containers composed of 30 individual cells about 492 cm^3 (30 cubic inches) in capacity. The containers were filled with W.R. Grace Forestry Mix, an artificial growing medium composed of 50% peat moss and 50% vermiculite. One Styrofoam block, containing 30 blue spruce seedlings, was sown for each of the five treatments. To facilitate the observation of symptom

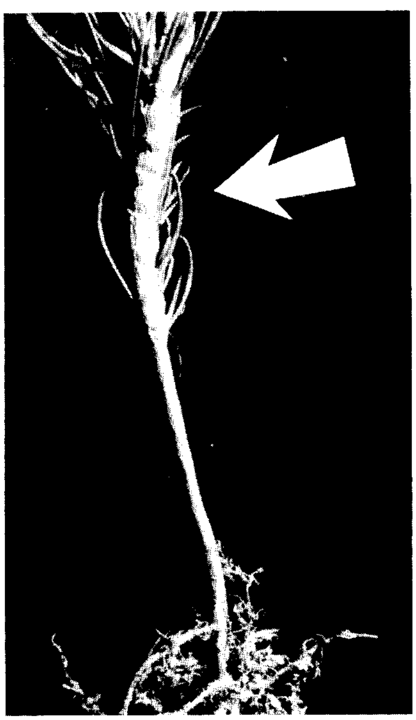

Figure 2—*Stem swelling in the hypocotyl above the cotyledon scar in blue spruce seedlings later in the growing season.*

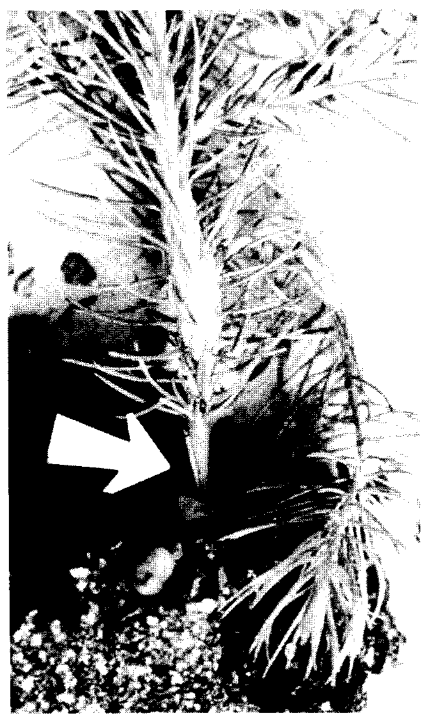

Figure 3—*Blue spruce seedling later in the growing season, showing constriction of the lower stem, which leads to mechanical weakness.*

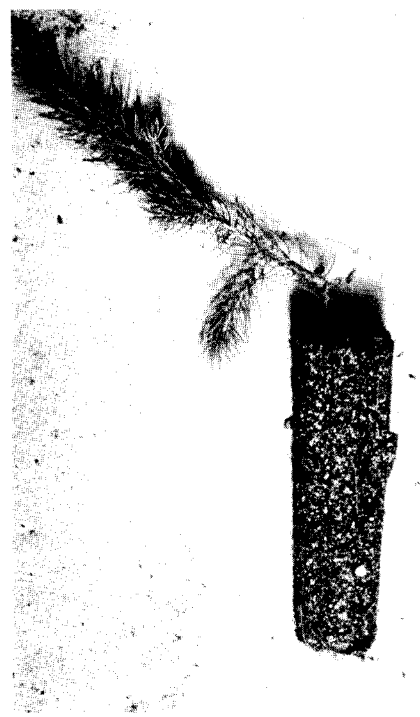

Figure 4—*Blue spruce seedling extracted from its container, with broken stem just below the area of stem swelling.*

development, a range of different sizes and ages was generated by a staggered sowing schedule: 6 different sequential sowing dates at 2-day intervals. This experimental design produced 180 seedlings per treatment (6 blocks of 30 seedlings each), or 900 seedlings for all 5 treatments.

Treatment 1 (control). The blue spruce seedlings were sown normally and grown under standard nursery procedures, but no fungicide was applied.

Treatment 2 (heat pasteurization of the growing medium). The growing medium was heated to 82 °C (180 °F) to volatilize any chemical contamination, and then the seedlings were grown under standard growing procedures with no fungicide applications.

Treatment 3 (captan fungicide). The seedlings were grown normally but were treated with a single application of captan 10 days after the last sowing. The fungicide was applied by portable sprayer at the rate of 1 pound of product per 3,000 square feet of seedlings.

Treatment 4 (dicloran fungicide). The seedlings were grown normally but were treated with a single application of dicloran fungicide 10 days after the last sowing, at the rate of 1 pound of product per 3,000 square feet of seedlings.

Table 1—*Time sequence of stem injury symptom development on blue spruce seedlings in a Colorado container tree nursery*

Observation date (time after sowing)	Symptomatic seedlings/treatment (cumulative %)				
	Control	Heat	Captan	Dicloran	Captan/ dicloran
24 days	0	0	0	0.0	0.0
32 days	0	0	0	14.4	0.0
39 days	0	0	0	24.4	6.1
46 days	0	0	0	27.2	17.8
53 days	0	0	0	31.7	28.3
60 days	0	0	0	33.8	30.0

Treatment 5 (captan and dicloran fungicide). The seedlings were grown normally and both captan and dicloran were applied at the rates stated above. Captan was applied 10 days after the last sowing, and dicloran 17 days after sowing.

Beginning at about 3½ weeks after the last sowing, the test seedlings were examined for both damping-off and stem symptom development at approximately weekly intervals. The seedlings were rated as either injured or healthy, and these ratings were recorded for a period of 60 days.

Results and Discussion

The weekly examinations revealed no damping-off, but blue spruce seedlings exhibiting the characteristic stem injury symptoms were first observed in the dicloran treatment about 2 weeks after the fungicide applications (about 1 month after sowing, table 1). Symptomatic seedlings were scattered randomly throughout the Styrofoam blocks, with damaged seedlings recorded in 14.4% of the individual cells.

One week later, during the second examination, symptomatic seedlings had increased to 24.4% of the cells in the dicloran treatment, but were also apparent in 6.1% of the captan/ dicloran treatment (table 1). The number of symptomatic seedlings gradually increased in both the dicloran and captan/dicloran treatments, until around 30 to 34% of the spruce seedlings were affected at 2 months after sowing. None of the seedlings in the control, heat, or captan treatments displayed any damage during the 60-day examination period (table 1).

This operational trial indicates that the dicloran fungicide treatment was phytotoxic to the young blue spruce seedlings when applied after sowing. Dicloran is normally used to control grey mold on older seedlings, so this postsowing application does not represent a normal, recommended type of application. Although dicloran injury is not documented in the published literature, this fungicide caused a similar type of stem swelling injury to spruce and hemlock seedlings in another container nursery in Washington.

Although captan apparently did not damage the seedlings in this trial, there have been several reported cases of captan damage in the literature. Captan was found to cause stunting of both roots and shoots of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) seedlings (2). A more recent *in* vitro study reports that captan levels above 500 ppm caused root and shoot stunting of red pine *(Pinus resinosa* Ait.) seedlings, with root injury being the most serious result (3). Carlson and Nairn (1) reported stunting and hypocotyl curling of both red pine and jack pine (*Pinus banksiana* Lamb.) container seedlings. It is unclear why captan was not harmful in these trials.

The fact that the seedlings were injured in the hypocotyl area of the stem may reflect the sensitivity of the young stem before the development of bark tissue. The exact reason for this stem swelling is unknown, but this type of symptom is often the result of girdling. When the photosynthate produced by the shoot is not translocated efficiently down the stem, a swelling develops immediately above the constriction. The stem below the girdle does not develop normally because the cells of the lateral meristem fail to divide at a normal rate. In this case the fungicide apparently damaged sensitive young stem tissues and either killed or damaged the cells of the phloem and lateral meristem, producing a partial girdle of the stem.

Conclusions and Recommendations

The fungicide dicloran can cause stem injury to blue spruce seedlings when applied as a postsowing treatment. Apparently the fungicide damages the meristematic tissue in the hypocotyl area, around the region of the cotyledon scar. A stem swelling develops above the damaged area, creating a mechanically weak area and causing seedlings to fall over or break during handling.

The seedling injury noted in this experiment reinforces a couple of standard rules for applying chemical pesticides. Fungicides or other pesticides should only be used for control of pests listed on the label, and any chemical should first be attempted on a small scale before operational use is considered.

Literature Cited

1. Carlson, L.W.; Nairn, L.D. 1975. Pentachlorophenol and captan effects on containerized red and jack pine seedlings. Tree Planters' Notes 26(1):32-34.
2. Denne, M.P.; Atkinson, L.D. 1973. A phytotoxic effect of captan on the growth of conifer seedlings. Forestry 46(1):49-53.
3. Kozlowski, T.T. 1986. Effects on seedling development of direct contact of *Pinus resinosa* seeds or young seedlings with Captan. European Journal of Forest Pathology 16(2):87-90.