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**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-125**

Proceedings: Intermountain Nurseryman's Association Meeting

**August 13-15, 1985
Fort Collins, Colorado**

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Abstract

Twelve invited papers were presented on a variety of topics of interest to nursery managers growing bareroot and/or containerized seedlings. Nine additional papers were presented in the form of small group workshops on weed control, seedling quality, and bareroot seedling fertilization.

Keywords: Tree nurseries, greenhouses, tree seedlings, containerized seedlings.

USDA Forest Service
General Technical Report RM-125

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Proceedings: Intermountain Nurseryman's Association Meeting

August 13-15, 1985

Fort Collins, Colorado

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Contents

Pesticide Precautionary Statement

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers—out of reach of children and pets—and away from foodstuff.

Apply pesticides selectively and carefully. Do not apply a pesticide when there is danger of drift to other areas. Avoid prolonged inhalation of a pesticide spray or dust. When applying a pesticide, it is advisable that you be fully clothed.

After handling a pesticide, do not eat, drink, or smoke until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If the pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Dispose of empty pesticide containers by wrapping them in several layers of newspaper and placing them in your trash can.

It is difficult to remove all traces of a herbicide (weed killer) from equipment. Therefore, to prevent injury to desirable plants, do not use the same equipment for insecticides and fungicides that you use for a herbicide.

NOTE: Registrations of pesticides are under constant review by the Federal Environmental Protection Agency. Use only pesticides that bear the EPA registration number and carry directions for home and garden use.

PROTECT

Use Pesticides Safely

FOLLOW THE LABEL

U.S. DEPARTMENT OF AGRICULTURE

Value of Windbreaks[1]

Sheridan I. Dronen[2]

Abstract.--Windbreaks are an important part of in the Great Plains. They are planted for a variety of reasons and provide both economical and esthetic benefits. This is a summary of some of the benefits and the importance of using adapted, high quality nursery stock.

Early settlers in the Great Plains found trees growing only in the drainageways and river bottoms. Due to the relentless wind, they soon recognized the need for windbreaks. They found that it wasn't an easy task to move trees from the river bottoms to the prairie, but with care it was possible. The benefits of windbreaks in the Great Plains have been recognized since these early days.

Starting with the Timber Culture Act of 1873 up to the present, millions of seedlings have been planted in windbreaks on the Great Plains. In South Dakota alone, over 150 million seedlings have been planted from 1935-85. These windbreaks are planted for a variety of reasons but mainly as a barrier to reduce wind velocity. Reducing the wind velocity alters factors of the microclimate, such as humidity and temperature, in the protected zone. Windbreaks conserve moisture because they reduce evaporation and transpiration in summer and trap snow in winter. Windbreaks protect farm and ranch homes, cultivated fields, gardens and orchards, livestock feedlots, and wildlife.

There have been many studies on the economic value of windbreaks. In a recent study in Saskatchewan, White (1984) found that a properly designed shelterbelt can reduce the heating of a typical farm home by $585 per year. This reconfirms an earlier study by Bates (1945) that showed about a 25 percent reduction in heating costs.

A study by Ames (1980) calculates the increased maintenance feed costs for beef cattle per degree of cold. This method shows a windbreak can reduce the maintenance feed costs for beef cattle by 10 percent on a winter day of 15°F and 15 mph winds. Savings are even greater as the temperature drops and the windspeed increases.

Dr. Brandle (1980) has published some interesting work in Nebraska on the benefits of field windbreaks. His studies show field windbreaks can increase winter wheat yields by 8 bu./ac. and soybeans by 4 bu./ac.

These studies and others show monetary benefits from planting windbreaks. How do you put a monetary value on raising a nice flower garden in the protected area of a windbreak on the windswept Plains? These nonmonetary values are also important reasons for windbreaks.

I want to switch gears a little now and talk about why we have good windbreaks and why we've been able to keep a good windbreak program going in the upper Midwest. I feel one of the most important factor is that we have a lot of high quality windbreaks and high quality windbreaks sell themselves. This quality is the result of research and information gathering that was started in the late 1800's and has continued up to the present.

During the 1890's, state agricultural experiment stations throughout the Plains established tree planting tests to determine the best adapted species. USDA field stations at Mandan, North Dakota; Cheyenne, Wyoming; Akron, Colorado; and Woodward, Oklahoma began tree planting experiments during the period 1910-20. This work is still the basis for our present windbreak planting program. The list of species (table 1) used in the 1916 shelterbelt project at Mandan isn't much different than the species that are most commonly planted today (table 2). This comparison is important because it shows us how limited we are in species selection. This is especially true for tall trees adapted to dry sites.

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[1]Paper presented at the Intermountain Nurseryman's Association Meeting, University Park Holiday Inn Hotel & Convention Center, Fort Collins, Colorado, August 13-15, 1985.

[2]Sheridan I. Dronen, Staff Forester, USDA, Soil Conservation Service, Huron, South Dakota.

Tall deciduous trees	Medium-height deciduous trees	Conifers	Shrubs
Green ash	Chokecherry	Ponderosa pine	Common buckthorn
Boxelder	Russian-olive	Scotch pine	Silver buffaloberry
Cottonwood	Tatarian maple	Eastern redcedar	Tatarian honeysuckle
American elm		Black Hills spruce	Siberian pea-tree
Siberian elm		Blue spruce	American plum
Hackberry			
Honeylocust			
Golden willow			

Table 1.--Cooperative Shelterbelt Project 1916-46
(George 1953)

Tall deciduous trees	Medium-height deciduous trees	Conifers	Shrubs
Green ash	Amur maple	White (Black Hills) spruce	American plum
Hackberry	Chokecherry	Blue (Colorado) spruce	Caragana
Honeylocust	Manchurian crabapple	Eastern redcedar	Lilac
Poplars	Russian-olive	Ponderosa pine	Peking cotoneaster
Siberian elm	Siberian crabapple	Rocky Mountain juniper	Silver buffaloberry
Willows		Scotch pine	Tatarian honeysuckle

Table 2.--Species used in the Northern Great Plains
(Dronen 1984)

How do we improve our windbreaks? The chances of finding many new species aren't very good; the real chance for improvement lies in improving the species we have and using the best known seed sources for seedling production. That's why the nurseryman is so important in the success or failure of our windbreak program.

Another area where the nurseryman is extremely important is in seedling grades. In the Dakotas' we have established minimum and maximum grades for nursery stock for all the species that are used in windbreaks. These grades were established from research and practical experience.

E. J. George (1973) found that there was significant differences in height and diameter growth of green ash with four grades of seedlings. His study was established in 1941. The four grades: 1, 2, 3, and 4 averaged 2.9, 1.8, 1.5, and 0.8 feet in height and .52, .33, .22, and .15 inches in diameter, respectively, at planting time. Grades 1 and 2 showed superior height and diameter growth over grades 3 and 4 after 29 years in the field. Regardless of the cause, genetic or bed density, seedlings having the larger stem diameter at one year continued to have that characteristic when grown for a second season in the nursery.

I like to use the comparison with the runt in a pig litter. It never catches up with the rest of the litter. In the nursery, seedlings that don't make grade should be thrown away. This is especially true for tall trees. Height is one of the most important factors for influencing the values of a windbreak because the area protected by a windbreak is 10 times the height. Therefore, every additional foot of height provides 10 feet extra width of area protected. In the George study (1973) there was about a 9-foot difference between the number one grade and the number four grade seedlings. This increased the width of the area protected by 90 feet!

For many people, planting a windbreak is a once in a lifetime experience. You, the nurseryman, can assure that adapted seed sources and high quality seedlings, properly graded, are used to ensure the best possible start and give the windbreak a good chance of being successful.

LITERATURE CITED

Ames, D., Livestock Nutrition in Cold Weather, Animal Nutrition & Health, pp. 6-7 and 38-39, October 1980.

Bates, C. G., The Value Of Shelterbelts In House-Heating. Journal Of Forestry, Vol. 43, pp. 176-196, 1945.

Brandle, J. R., the Role of Microclimate in Energy Use Efficiency, Paper No. 6150, Journal Series, Nebraska Agricultural Experiment Station, November 1980.

Brandle, J. R., B. B. Johnson, and D. D. Dearmont, Field Windbreak Economics, Paper No. 6966, Journal Series, Nebraska Agricultural Experiment Station, 1982.

Dronen, S. I., Windbreaks In The Great Plains. Northern Journal Of Applied Forestry, Vol. 1 No. 3, pp. 55-59, September 1984.

George, E. J., 31-Year Results In Growing Shelterbelts On The Northern Great Plains, USDA, Circular No. 924, August 1953.

George, E. J. and A. B. Frank, Graded Nursery Stock In Shelterbelt Type Planting Evaluated Over 29-Year Span. Tree Planters' Notes, Volume 24, No. 1, pp. 30-32, 1973.

White, Robert, Shelterbelts Help Cut Heating Costs. Farmers Light & Power, February 1984.

In-Bed Herbaceous Windbarrier Produced More Ponderosa Pine Seedlings[1]

Richard W. Tinus[2]

Abstract.--There are currently no windbreaks at the Albuquerque Tree Nursery, but experience at other nurseries indicates windbreaks can be highly beneficial. To test the concept quickly without erecting or growing anything permanent, one drill row of oats was sown per bed when the rest of the bed was sown to ponderosa pine. The oats, which were maintained at 30 cm height by mowing, reduced wind velocity at ground level by 79%. In spite of a 25% loss of seedbed space (row 8 to planted oats and row 7 to competition from the oats), there were 55% more seedlings per running meter of bed with the windbarrier (6 rows) than without the windbarrier (8 rows). With the windbarrier, increases in seedling fresh weight and epicotyl height, and greener color were observed, but variability was too great for the differences to be significant. Windbarriers in adjacent beds across a section had no significant cumulative effect.

INTRODUCTION

Strong winds can be highly damaging to young seedlings. Since most nurseries experience strong winds at least occasionally, some form of wind protection is usually needed (Tinus 1978). Agronomic studies have also shown improved crop growth behind windbreaks even in situations where the wind is not strong enough to cause direct damage (Tinus 1976). However, the effects of windbreaks are not all beneficial, and careful planning is needed to maximize benefits while minimizing unwanted side effects (Read 1964, Stoeckler 1962).

Any windbreak has three primary characteristics: height, density, and orientation. The primary effect is reduction of wind velocity on the lee side. The pattern of wind velocity reduction is independent of barrier height, but the protected area is proportional to the height; therefore, the effect of a windbreak at any distance from it can be measured in terms of multiples of barrier height (H) (Read 1964). For complete protection, the array of barriers should be spaced about 10 H apart. That means a row of trees 15 m tall will protect an area out to 150 m from the trees, whereas a 1.3-m snow fence will protect only 13 m.

Trees and snow fences have been the main windbreaks used in nurseries. Trees have the disadvantage that they take years to grow to a useful size, and they may harbor pests that attack the crop trees. To be effective, snow fences must be erected in the middle of each section, where they tend to get in the way of farming operations and are a nuisance to put up and take down.

The Albuquerque Tree Nursery is currently devoid of windbreaks, but some small-scale experiments and observations indicate that windbreaks might be useful. In a recent nursery study, Douglas-fir, white fir, and Engelmann spruce seedbeds that were covered with snow fence on sideboards produced more and larger seedlings, but there was no apparent response by ponderosa pine. However, for protection from rabbits, the whole experiment was surrounded by 1-m-high, 6-mm hardware cloth, which is also an effective windbreak; and the growth of ponderosa pine within and close to the enclosure was clearly better than at distance beyond the windbreak influences.

From the apparent benefit of wind protection without significant shade, without interfering with cultural operations and at low cost, came the idea for an herbaceous windbarrier to be planted in one drill row of each bed of ponderosa pine. Oats were selected, because it is a cool-season grass that would reach an effective height quickly in the 1-0 season and die overwinter. If mowed to prevent heading out, it would not become a weed problem.

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[1]Paper presented at the Intermountain Nurseryman's Association Meeting, August 13-15, 1985, Fort Collins, CO.

[2]The author is principal plant physiologist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff, AZ.

Figure 1.--Ponderosa pine at Alburquerque Tree Nursery in July of the first season with an oat windbarrier, just before mowing to 30 cm.

MATERIALS AND METHODS

At Albuquerque Tree Nursery, the beds are oriented north to south, almost perpendicular to the strongest winds during the growing season. In May 1983, the seven beds of one nursery section were sown to ponderosa pine in seven drill rows. The eighth (westernmost) drill row in each bed was sown to Cimmaron oats, a tall-stemmed variety of Texas origin (fig. 1). The oats were sown fairly thick (about 65 seeds per running meter) to insure a windbarrier of adequate density. Another nursery section sown entirely to ponderosa pine with no oats served as the control. Windbreak and control sections were separated from each other and to the sides by fallow sections. Windbreak and control sections were replicated twice, all on about 2 ha of the nursery that were reasonably uniform in soil texture. In the middle of each windbreak and control section, a totalizing cup anemometer was installed, recessed into the ground so that the cups were just above ground level at the expected seedling crown height.

Seedling cultural treatments, such as irrigation, fertilization, and weed and pest control, were the same as elsewhere on the nursery. When the oats began to head out at 50 cm in height at the end of June (fig. 1), they were mowed to 30-cm height.

The four anemometers were read weekly throughout the first and second growing seasons. At the end of each growing season, two randomly located but widely spaced transects were laid out perpendicular to the sections. The two transects across two field replications were treated as four block replicates for statistical purposes. All of the seedlings in a 30-cm strip were lifted by hand and kept separate by drill row.

The seedlings in each sample plot (30-cm strip of drill row) were counted and bed density computed. On a random subsample of 10 seedlings (or fewer, if there were not 10), fresh weight, epicotyl height, and foliage color were measured. Foliage color varied from dark green to yellow and was measured by an index keyed to the following Munsell standard colors (Anon. 1977):

Index	Color	Munsell code	
4	dark green	7.5 G	4/4 to 2/4
3	light green	7.5 GY	5/6 to 5/8
2	yellow green	5.0 GY	6/6
1	yellow	2.5 GY	7/6 to 7/8

The color index was treated as a continuous variable, as were the other measurements, and analyzed as a randomized block design with beds within treatment and rows within beds treated as split plot and split-split plot factors, respectively. Only six rows per bed were analyzed to balance sample size between treated and control blocks.

RESULTS AND DISCUSSION

Reduction of Wind

After the oats had reached about 50 cm in height by the beginning of July (fig. 1), and for the remainder of the first growing season after the oats had been mowed, the oat windbarrier reduced surface wind by 74%, or to only 26% of what it was with no windbreak. This result was as expected for a moderately dense windbreak at a distance of about 2.5 H (Tinus 1976). The oats

remained standing overwinter and throughout the second growing season, during which they reduced surface wind to 21% of total wind with no protection. Therefore, for at least 16 months, the oats were a highly effective windbreak within about 10-15 cm of the soil surface.

Main Effects of Windbreak

Seedling numbers were strikingly affected by the oat windbarrier. Competition and shading from the oats (in row 8) was so strong that seedlings grew poorly in row 7. Therefore, for the following comparisons, it was assumed that no usable trees would be produced in rows 7 and 8 with the windbarrier. To simplify analysis, rows 1 through 6 with a windbarrier are compared with rows 1 through 6 without the windbarrier.

At the end of the first season, the differences in seedling number and size, with or without a windbarrier, were not significant. However, by the end of the second season, bed density without a windbarrier was 104 seedlings per square meter, but 215 per square meter with a windbarrier (106% greater); and seedlings per lineal meter of bed (which includes rows 7 and 8 where there was no windbarrier) was 127 and 197, respectively, or 55% greater. Fresh weight and epicotyl height were greater and foliage color greener with a windbarrier than without in some, but not all, of the replications. Variability was too great for these differences to be significant.

Cumulative Effect

If linear multiple windbreaks are spaced closely enough so that the effect of one is not completely dissipated before the next one is encountered, there may be a cumulative effect up to as many as four windbreaks (Read 1964, Tinus 1976). In this experiment, such an effect was sought by comparing beds within treatments; however, no significant differences were found, except that at the end of the first year, foliage color tended to be yellower in the eastern beds than in the western, and the difference in color was greater in beds without a windbarrier than with one. Thus, there is little evidence of any cumulative effect.

Within-Bed Effects

At the end of both the first and second seasons, there were distinct differences in seedling number, size, and color by row within bed (fig. 2). Number of seedlings followed no pattern

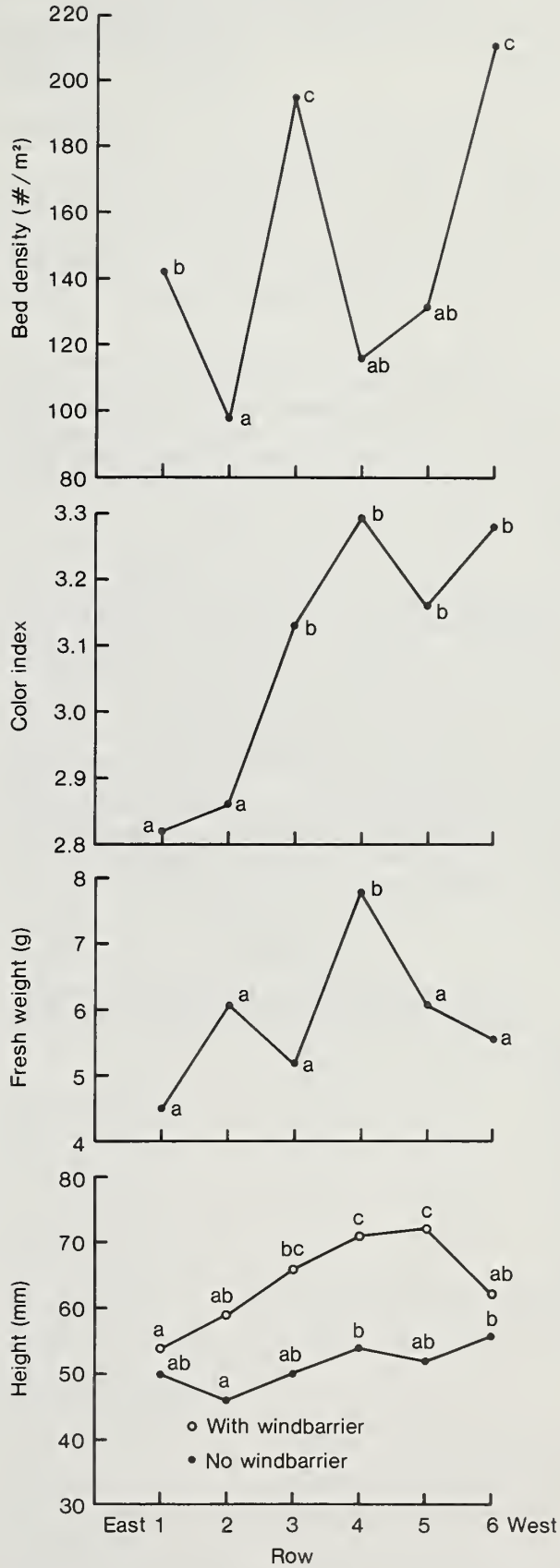

Figure 2.--Number, size, and color of 2-0 ponderosa pine seedlings as a function of row within bed. Bed density, color, and fresh weight showed similar patterns with or without a windbarrier. Points on a given line with the same letter are not significantly different at p=0.05 by an F-protected LSD test.

that could be related to the experiment; but the pattern was the same with or without the windbarrier, in both first and second seasons. It may have been caused by nonuniform sowing or seed covering.

With the windbarrier, epicotyl height and fresh weight were largest in the middle rows and declined on either side creating a distinct "breadloaf" effect. This is evidence of the competition from the oats and was expected. Growth and tree numbers were so strongly depressed in row 7 (adjacent the oats in row 8) that this row was deleted from calculations of size and number of seedlings produced with the windbreak.

Although there were some significant differences in beds without a windbarrier, there was not a clear pattern. Sometimes a breadloaf pattern is observed in beds of not only tree seedlings, but of horticultural and agronomic crops (Tinus 1976). As the seedlings gain height and foliage density, they become a windbarrier in themselves and protect their neighbors to the lee side.

Seedling color tended to be greener in the middle and western rows and more chlorotic in the easternmost rows, with or without a windbarrier. In the first season, the effect was more pronounced without a windbarrier than with one. Sometimes growth in the outermost rows of a bed is poorer because of exposure, wheel compaction of the alley between beds, or sloughing of the edge of the bed. However, there was no evidence for any such conditions in this experiment. A second possible explanation is that the most detrimental winds come from the east. If so, local weather records could indicate the time of year and circumstances under which windbarriers would be most useful.

CONCLUSIONS

More ponderosa pine seedlings were produced in six rows per bed with an oat windbarrier than were produced in eight rows without it. The effectiveness of the windbreak was due in part to seedbed orientation, because the beds are laid out perpendicular to the prevailing strong winds. This technique shows promise as a means for a nursery to obtain wind protection for the seedbeds quickly with little capital expenditure. As with all innovations, however, it should be treated on a small scale on an area typical of the nursery as a whole to determine if the benefits warrant the costs, before being applied to the whole nursery.

LITERATURE CITED

Anonymous. 1977. Munsell color charts for plant tissues. Kollmorgen Corp., Baltimore, Md.

Read, R. A. 1964. Tree windbreaks for the central Great Plains. Agriculture Handbook 250, 68 p. U.S. Department of Agriculture, Washington, D.C.

Stoeckler, J. H. 1962. Shelterbelt influence on Great Plains field environment and crops. Forest Service Product Research Paper 62, 2 p. U.S. Department of Agriculture, Washington, D.C.

Tinus, R. W., editor. 1976. Shelterbelts on the Great Plains: Proceedings of the symposium. [Denver, Colo., April 20-22, 1976] Great Plains Agriculture Council Publication 78, 218 p.

Tinus, R. W. 1978. Shelterbelts for nurseries. p. B-154-164. In Proceedings of the Western Forest Nursery Council and Intermountain Nurserymen's Association Workshop [Eureka, Calif., August 7-11, 1978]. R. W. Gustafson, editor. U.S. Department of Agriculture, Forest Service, State and Private Forestry, San Francisco, Calif.

Administrative, Economic, and Technical Observations in Developing and Maintaining an Effective Weed Control Program[1]

Al Myatt Michael Vorwerk [2]

Weed control is an important part of a nursery operation. As managers we should be concerned with not only the technical aspects of an effective weed control program but influence we have on the "human resources" as well.

As managers we spend between 60 to 80 percent of our operations budget on human resources-salaries. And according to the July 11, 1985 issue of the Wall Street Journal, titled, "Loyalty Ebbs at Many Companies as Employees Grow Disallusioned", we may have some room for improvement. The graph shows that since 1970 there has been an increased dissatisfaction in all management levels of the work force. Sick leave is up to over 13%.

What does this have to do with weed control? An effective weed control program is carried out by people who will do, not by people who can do.

All the technical knowledge in the world is of little importance if it is not applied, or applied wrong, or applied at the wrong time under the wrong conditions because of lack of desire to be effective on the part of the employee. This intangible inner drive called motivation is directly related to the degree of employee commitment to the job and the organization.

As a manager what do you do to effectively utilize this resource? Does your interviewing program allow your staff to assist in hiring the person they will be supervising or working with? As a supervisor were you trained in the art of interviewing? Do you have written job descriptions and have an understanding of what type of characteristics you are looking for in an applicant? Do you hire someone to fill a specific beginning level position without considering him for higher level positions.

Do you have an effective training program for teaching the employee the technical skills needed for his job? Does your program include communications and team building skills, policies and functions of the organization and skills needed for supervision and promotion?

Do you have a written annual plan or work that the staff has helped you develop?

Do you have a review system that allows you to work with an employee on what needs to be accomplished? Provide them with different levels of goals so that the work is challenging while evaluating their progress on a regular basis.
Does your program reward them for their success? Remember even if money is limited, praise is free.

The skills and knowledge acquired as a supervisor are learned in most cases. There are a few of us that have that natural ability, but for the most part most supervisors are promoted because they were super-workers not because of their ability to supervise.

As a supervisor you need to find out what motivates an employee. Remember managers do not motivate employees. Motivation is something that a person has within him - he brings it with him. A manager can stimulate motivation through training, planning methods and rewarding accomplishment.

Last year the Oklahoma Forestry Division spent $27,283.57 on a weed control program. Of the total cost $18,241.71 was labor and $9,041.86 was spent on chemicals:

Table I. Three Year Cost Data of Oklahoma's Weed Control Program

	Total Hrs. & Costs By Year		
	FY83	FY84	FY85
Labor (Hrly) on chemical control	1,284.5	1,691	1,530.25
Labor (Hrly) on hand weeding	3,255	2,988.5	2,862
Total Hours	4,539.5	4,679.5	4,392.25
Labor ($) on chemical control	7,920.78	8,987.28	8,216.26
Labor ($) on hand weeding	11,359.95	10,448.58	10,025.45
Total ($) of labor ($8/hr. for Sr. Technician and $3.35/hr. temporary labor)	19,280.73	19,435.86	18,241.71
Chemical Cost	5,334.73	9,109.00	9,041.86
Total Cost	24,615.46	28,554.86	27,283.57
Total Seedling Production	1,562,300	1,191,650	1,685,600
Cost Per Seedling	.01575	.02396	.0162

1. Paper presented at the Intermountain Nurseryman's Association Meeting, Fort Collins, CO, August 13-15, 1985.

2. A.K. Myatt is Area Forester for the Oklahoma Forestry Division. Mike Vorwerk is Nursery Manager for the Oklahoma Forestry Division.

The following information is a comparison of hand weeding vs. hand weeding and chemical control on 25 acres based on data from a 1981 study at the Norman Nursery done by Dr. Larry Abrahamson, SUNY.

Table II.

Hand Weeding Only	$133,000.00/yr (est)	
Chemical Control + Hand Weeding	27,283.57/yr	(Actual cost for 1985)
Savings/Year	105,716.43	

We like to think the money was well spent. However, we will continue to work closely with the staff in the manner I have discussed to help each individual become more informed to further reduce costs, both in labor and chemicals.

I feel that management should behave as if employee development is the lifeblood of the organization. This is not to suggest that employee development is of more importance than operations or accounting efforts. It is rather to say that the growth of the organization is dependent upon the growth of its employees.

One observation that I might mention is, when the human resouce is poorly utilized so is the equipment and the supplies, (in this case chemicals), that are purchased to do the job. This generally means that both labor and materials cost more to complete the project in a less than acceptable manner.

Another area that is important to everyone is: Why have an effective weed control program? Each individual on the team needs to know and appreciate what the purpose of what they are doing is all about. Or, why should we bother?

An effective weed control program will help:

A. Reduce fertilizer costs.
B. Reduce competition in the seed bed yielding an increased quality crop.
C. Increase survival of the germinating seed.
D. Reduce the number of cull seedlings at the time of harvest.
E. Allow more effective use of irrigation water.
F. Reduce weed seed sources for future crops.
G. Decrease problems with lifting and grading seedlings.
H. Increase esthetics, improve attitudes, organization and funding.

Solving a complex problem like weed control requires a wide range of technical methods and cultural practices. The following are methods and techniques utilized at the Oklahoma State Nursery.

Treflan is applied to all areas that are planted to seedling crops except for a few non tolerant species. The herbicide is applied 2-3 weeks prior to planting.

Pre-emerge herbicides such as Mowdown, Devrinol, Dacthal, Goal and Ronstar are applied over the tops of the seedlings on all species grown. The herbicides are applied with tractor mounted spray tanks and the granular forms are applied with a Gandy fertilizer spreader.

Mechanical weed removal methods are required on a small scale, because the pre-emerge herbicide will not control all the weeds.

Hoeing: Hoeing is used on some weed crops in the more open grown species and along the outside edge of the seedling beds. Triangular shaped hoe blades seem to work the best.

Hand pulling: The weeds are removed from the ground by utility knives with curved blades.

If the weeds have started to seed out, they are bagged up and removed from the field.

Drop tubes have been developed on a tractor mounted spray boom to spray pre-emerge or contact herbicide along irrigation lines. The boom can easily go over the top of the riser while the drop tube applies the herbicide from the proper height. With slight modifications the drop tubes could be used to spray aisles on tall species.

A tractor mounted spray tank was built for spraying Roundup herbicide. The tank has a center and side mounted boom. The tank also has a hand gun for spraying open areas such as along windbreaks, fronts of beds or along irrigation lines. It can also be used for spot spraying.

Hand held spray tanks are used extensively for weed control. The $1\frac{1}{2}$ - 2 gallon tanks can easily be carried by the employee. Roundup is used in the tanks. The tanks have long wands so the employees can easily spray weeds between the seedlings. Cones are placed over the nozzles so the herbicide is targeted just to the weeds.

Weedwicks are also extensively used for weed control. Roundup at a 33% rate is used in the wicks. The wicks can be used in tight places between seedlings. The sponge type weed wick head seems to work best. This type gives the best coverage and eliminates dripping.

A purple dye is used in the hand sprayers and weedwicks. The dye helps with visual metering of the Roundup. It was specifically developed to be mixed with Roundup. The dye is produced by Becker-Underwood in Ames, Iowa.

A $\frac{1}{2}$" layer of sawdust mulch is applied to several species of hardwoods during mid-summer. The sawdust helps to moderate the soil temperature and has some weed control benefits. The sawdust is applied with a manure spreader when the seedlings are 6-8" tall. This practice does not work well on the conifers because it has a tendency to bury them, the sawdust won't sift through the needles. The sawdust does not affect the fertilizer requirements of the seedlings.

Cover crop is planted on all fallow areas. The cover crop reduces the weed crop that might come in, prevents wind erosion and increases the organic matter. Sudan is planted in the spring and wheat is planted in the fall.

Weedeaters are used to control the weeds from seeding out on weeds around the complex, windbreaks and other areas that can't be mowed or sprayed.

Methyl Bromide fumigation is used on a limited basis at the Oklahoma State Nursery for weed control.

In the past several years with increased costs in labor, herbicides have been the main focal point. The Oklahoma Forestry Division started its herbicide program in the fall of 1977. Dr. Larry Abrahamson, SUNY, under funding from the U.S. Forest Service drew up a three year program to test and register chemicals for nursery use. Larry has continued with the Oklahoma Forestry Division under contract with SUNY. The following summary in Table III. shows what herbicides are currently operational in the Oklahoma Nursery:

Table III.
Herbicides Applied at the Oklahoma Nursery

Herbicides	Species	Rate (Lbs. AI./AC.)
Mowdown/Devrinol Tank Mix	All conifers, Lacebark Elm, Arborvitae, Russian Olive, Autumn Olive, Green Ash and Baldcypress	3.0/1.0
Goal	All conifers: Loblolly, Shortleaf, Scotch, Austrian, Ponderosa and Virginia Pines, Red Cedar and Arborvitae	.5
Dacthal/Devrinol Tank Mix	Euonymus, Hackberry, Multiflora Rose, Redbud, Catalpa, Sand Plum, Silver Maple, Osage Orange, Mulberry, Black Walnut, Pecan and Bur Oak	10.5/1.0
Ronstar or Treflan, Granular	Black Locust	1.0
Treflan (Pre-Plant)	All species except Euonymus, Hackberry, Lacebark Elm, Sand Plum, Sycamore, Catalpa and Silver Maple	1.0
Mowdown/Devrinol Tank Mix or Goal	Irrigation lines and along windbreaks	3.0/1.0
Roundup	General Use	2-3 oz/gal.

Dr. Larry Abrahamson has continued his research and the following is an outline of the current work that he is doing (Table IV). He has worked closely with the Oklahoma Forestry Division over the past 8 years to develop the herbicide program we have today. Thanks to everyones efforts and his direction and research we have saved thousands of hours in labor and increased the quality of our seedlings.

A quick look into the future shows that continued work needs to be done in finding chemicals that can be applied to some of the sensitive hardwoods.

Table IV.
Herbicide Research 1985, Oklahoma Nursery
Coordinated Through State University, New York

Species	Herbicide Tested	Rate (Lbs AI./AC.)
Pecan	Devrinol (50W)	1.5
	Mowdown (80W)	3.0
	Caparol (80W)	1.0
	Dacthal (75W)	10.5
	Devrinol/Mowdown (Tank Mix)	1.0/3.0
Sycamore, Catalpa, Lacebark Elm and Redbud	Enide (90W)	4.0
	Treflan (4EC)	.75
	Dacthal (75W)	10.5
	Devrinol (50W)	1.5
	Ronstar (2G)	1.0
	Caparol (80W)	1.0

Each chemical was tested post seed, post germination and post seed plus post germination. Each was tested at 1X and 2X rates.

It is also important to have several herbicides for each species so that a rotation can be set up. This will reduce the chances of different weed species becomming resistant to the chemicals.

To increase the effectiveness and versitility of chemicals, "underleaf spraying equipment" needs to be perfected and utilized. This will allow us to place a wider varity of chemicals on specific areas of the plants, weeds, or just on the soil. This should help:

A. Reduce hand weeding costs, or make them non-existant.
B. Reduce the cost of chemicals, in that the spray is directed to areas where it is most effective.
C. Reduce damage to the plants from stunting or decreased vigor.
D. Help apply chemicals to sensitive plants that we currently do not have control methods for.
E. Allow more than one cultural practice to be carried out at one time. ie. underleaf spraying and cultivation, or underleaf spraying and fertilization.
F. Allow more than one chemical to be sprayed at a time (example - spray a contact such as roundup as needed along with a pre-emergent).

References

Broadwell, Martin M. 1979. Moving up to Supervision. 163 p. CBI Publishing Company, Boston, Mass.

O'Boyle, Thomas F. Loyalty Ebbs at Many Companies as Employees Grow Disillusioned. The Wall Street Journal July 11, 1985, 25 p.

Waters, Maureen. Motivation: Tapping the inner drive. Grounds Maintenance. March 1985.

Nursery Research: A Practical Approach[1]

G. Bruce Neill[2]

Abstract.--A summary is given of research activities being carried out at the PFRA Tree Nursery, Indian Head, Saskatchewan. Main areas of investigation include propagation, tree improvement, weed control, soils, entomology and pathology.

INTRODUCTION

The PFRA Tree Nursery has produced and distributed over 450 million seedlings since its establishment in 1902. The mandate of the Nursery remains much the same today as when it started, that is, to provide trees for shelter to farmers in the Canadian prairie provinces. Currently, approximately 25 species are produced, comprised of both coniferous and deciduous stock. Almost half of our yearly production is one specie, namely caragana (*Caragana arborescens*). The trees are used as farmstead shelterbelts for protection of yards, as field shelterbelts for soil erosion control and snow management, and as roadside belts for snow control.

Almost 40 years ago, the Nursery established a research component responsible for conducting studies on tree breeding, physiology and pest control. Since that time the research section has undergone a number of changes. Today this section is composed of five units, namely, Propagation, Soils, Herbicides, Entomology and Shelterbelt Studies. There are a total of eight full time and six seasonal or casual personnel in the section. This represents about 16 percent of the total allotment for the Nursery. The mandate of the group is to solve the problems associated with growing trees on the prairies and to determine the effects of these trees on prairie agriculture. Each year numerous practical studies are completed and reported in our Annual Report. Recommendations are implemented by our Production and Extension Sections.

Along with the research mandate, the Investigation Section is also responsible for overseeing most technical operations on the Nursery. For example, herbicide, insecticide and fungicide applications are supervised and/or conducted by Investigation personnel. Implementation of test results therefore, becomes fairly straightforward.

Examples of areas of research being conducted by each of the five units in the Investigation Section follow:

Propagation

Bill Schroeder is in charge of both the Propagation and Soils Units. Our Propagation technician is Dan Walker. The Propagation Unit is the largest group with the greatest diversity of studies. Examples of trials conducted in 1985 include such things as dates, rates and depth of sowing seed, effects of mycorrhizae, root wrenching treatments, fall vs spring sowing, propagation techniques for poplar cuttings, evaluation of seedling maturity, ethylene adsorbant for seedling storage, freezer storage techniques, green ash provenance trials, USSR pine breeding trial, USSR Siberian larch provenance trial, and packing material tests. Other areas of interest include seed storage, seed stratification, chemical fruit drop, chemical defoliation, container culture technique and others. For details on these and many other related topics, refer to our Annual Report.

Soils

The Soils Unit is responsible for providing service support to the Production Section by conducting soil analysis of all fields. Our Soils technician is John Cruickshank. Recommendations are provided on the basis of fertility trials conducted at the Nursery. Irrigation scheduling has also been reviewed with hopes of implementing a more precise system.

Herbicides

Bruce Neill is in charge of both the Herbicide and Entomology Units. Our Herbicide technician is

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[1]Paper presented at the Intermountain Nurseryman's Meeting (Colorado State University, Fort Collins, August 13-14, 1985).

[2]G. Bruce Neill, Head, Investigation Section, Tree Nursery, PFRA, Agriculture Canada, Indian Head, Saskatchewan.

Lyle Alspach. Current studies include screening herbicides for preemergence weed control in sowings of Colorado spruce, Scots pine, white spruce, honeysuckle, green ash and caragana, and in poplar and willow hardwood cuttings. Post-emergence weed control in villosa lilac and caragana is also being persued. Herbicides for use in newly planted and established shelterbelts are continually being screened. The Nursery now has herbicide recommendations for over 70 percent of our annual production and has one to four people involved in herbicide applications throughout the growing season.

Entomology

Don Reynard is the technician working in the Entomology-Pathology Unit. Studies dealing with pesticide efficacy, life history, pheromones and fungicide efficacy are conducted yearly. Currently, much work is being done on pheromones for monitoring and control of the cottonwood crown borer (Sesia tibialis), and the spring cankerworm (Paleacrita vernata). Insecticide trials are conducted on pests as they arise. In 1985, insecticides were tested for control of the cottonwood crown borer, spruce budworm (Charistoneura fumiferana), blister beetles (Lytta spp.) and the willow shoot sawfly (Janus abbreviatus). Fungicide trials are conducted for control of storage molds, and poplar cuttings diseases. The Saskatchewan Dutch Elm Disease survey is also supervised by the Entomology Unit.

Shelterbelt Studies

John Kort heads this new unit which started in 1984. Studies will be conducted to support our Extension Section, who are responsible for promoting the use of shelterbelts on the prairies. Effect of shelterbelts on microclimate, crop yields, snow distribution and other effects will be of major concern. Potatoes, canola, safflower and wheat are currently being evaluated for their response to shelter. Various shelterbelt species and designs are also being tested for their potential in a soil conservation system.

CONCLUSION

All studies conducted at the Nursery have a practical origin. Through the last 40 years we have been able to build up a technical support staff for our Production and Extension Sections. Although our trials are aimed at solving our own problems, results often apply to other nurserymen. We encourage others to tour our operation and to call on us for advice. Yearly summaries of all studies can be found in our Annual Report which can be obtained by writing the author.

Soil Compaction: Effects on Seedling Growth[1]

Steven K. Omi[2]

Abstract.--The degree to which a compacted soil affects seedling survival or growth varies according to soil texture, organic matter, moisture content, tree species, and degree of compaction. Soil compaction generally restricts root growth and can inhibit shoot growth. In nurseries, compaction may be rare above the 15-cm depth because nursery soils are cultivated each year; however, below 15 cm compaction is relatively common, and is especially noticeable when drainage is impeded for long periods. The machinery used to manage the crop, the ability to control irrigation and fertilization, and the alternatives for tillage are all important aspects of nursery soil management affecting soil compaction.

INTRODUCTION

This report is the result of a need, expressed by Nursery Technology Cooperative (Oregon State University) members, in particular seedling users, for a literature search on the effects of soil compaction on seedling growth. However, compaction is also of concern to nursery personnel: in an OSU Nursery Survey, compaction was considered a problem by 62 percent of the nurseries surveyed and, relative to all other soil-related problems, was ranked first or second in importance by 24 percent of respondents (Warkentin 1984). Although soil compaction in agricultural crops has been extensively studied (Rosenberg 1964; Greacen and Sands 1980), little information has been published regarding the problem of compaction of forest nursery soils. It is the purpose of this report to review the effects of compaction on soil and seedling growth.

COMPACTION DESCRIBED

Simply stated, soil compaction is a decrease in volume for a given mass of soil (McKibben 1971) as a result of an applied load, pressure, or vibration. It produces rearrangement of soil aggregates and particles, and changes in soil properties (typically, increased bulk density or soil strength, or decreased porosity). Because compaction status of a soil influences air, water, and temperature relationships, it can affect all stages of crop production (McKibben 1971). The energy required to compact soil comes from a variety of sources including rainfall, irrigation spray, foot traffic by animals and people, plant roots, and weight of the vegetation and soil; a significant compacting force is produced by the machinery used to manage and harvest the crop (Greacen and Sands 1980). Whatever the cause, soil compaction may be characterized via several means, including bulk density, soil strength, permeability, and visual observations.

Bulk Density

Bulk density (usually expressed in grams per cubic centimeter) is found by determining the dry weight of soil occupying a known volume (solids plus pore spaces).[3] Bulk-density measurements are commonly used because of their relative ease of sampling, insensitivity to moisture, and known relationships with tree growth (McNabb 1981). The bulk density of most nursery soils is approximately 1.3 g/cm^3, ranging from 0.9 g/cm^3 in sands to 1.6 g/cm^3 in clay loams (Day 1984).

Generally, four methods are used to measure bulk density: core, excavation, clod, and radiation. In the core method, soil cores are collected in a sampler of known volume. This relatively simple procedure does not require complex equipment and leaves the natural soil structure of the extracted core intact so it can be used for other measurements (Adams 1983; Flint and Childs 1984). However, the procedure is time consuming, results can be difficult to obtain in the field, and the presence of large rocks and root fragments can bias the sample (Flint and Childs 1984). In the excavation method, the mass of soil excavated from a hole

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[1] Paper presented at the 1985 Intermountain Nurseryman's Association Meeting. [Fort Collins, Colorado, August 13-15, 1985].

[2] Research Assistant, Nursery Technology Cooperative, Department of Forest Science, Oregon State University, Corvallis, Oregon. Paper 2050, Forest Research Laboratory, Oregon State University.

[3] Particle density, another expression for describing soil weight, is the dry weight of soil per solid (excluding pore space) volume.

is divided by the volume of the hole (measured by filling the hole with material of known density or volume, such as water or sand). Like the core method, the excavation method is relatively simple and is suitable for soils having larger coarse fragments. Its disadvantages include the time lag between field sampling and results, accuracy in determining the volume of the excavated hole, and disturbance of the soil sample such that it cannot be used to assess other soil properties (Blake 1965; Adams 1983). In the clod method, clods are removed, weighed, coated with a water-repellent material (such as paraffin), and then immersed in water to determine clod volume. This simple proce dure is useful for hard soils; additionally, the clods can be preserved for other measurements as long as the test is done carefully, to maintain clod structure. However, this method is time consuming; and potential bias exists because of the tendency to select samples which are firm enough and of adequate size (Freitag 1971) and because the measurement can exclude the pore spaces between clods (Adams 1983; Flint and Childs 1984).

Whereas the core, excavation, and clod methods disturb the soil, nuclear density probes can nondestructively sample for bulk density. The ability of radioactivity to penetrate the soil reflects the density of soil particles; as soil density increases, the ability to penetrate decreases (Freitag 1971; Adams and Froehlich 1981). The advantages of this method are that many measurements can be taken rapidly in the field, soil disturbance is kept to a minimum, and the same sampling site can be measured more than once. Additionally, since changes in water content cause changes in density, nuclear probes can be used to assess seasonal changes in water content. The disadvantages include the need for expensive equipment, calibration curves to convert counts of radiation to bulk density, and minimizing human exposure to radiation. However, recent improvements in radiation technology make this a worthwhile method for land managers to consider as an alternative to or in combination with conventional techniques.

Although soil bulk density is the most frequently used measurement to assess compaction, it is only an indirect measure of how change in soil physical property affects root growth (McNabb 1981) and gives little information on pore-size distribution or particle arrangement (Freitag 1971). Soil strength (mechanical resistance) and aeration, two significant factors limiting growth in compacted soils and whose effects are often difficult to separate (Warkentin 1984), are the main physical properties affected by increases in bulk density.

Soil Strength

Soil strength refers to the mechanical resistance of soil to an applied force. Shear tests (measuring the torque required to shear the soil along the surface) and penetration tests (measuring the weight required to push a tip, plate, or footing of some type into the soil to a certain depth) can assess soil strength with simple procedures; large areas can be measured quickly, and because soil is only minimally disturbed, several measurements can be taken near the same sampling point (Freitag 1971; Adams 1983). Although both shear and penetration tests seem equally suitable for assessing soil compaction (Freitag 1971), it is important in both cases to standardize procedures and equipment so that results can be reproduced. Soil properties such as moisture or texture (Adams 1983; Warkentin 1984), shape of the penetrating or shearing element, and rate at which elements are advanced into the soil all can affect results (Freitag 1971).

Soil strength typically increases when a soil is compacted, and strength tests have been significantly related with bulk density measurements. Gifford et al. (1977) found soil-core bulk density to be significantly correlated with pocket penetrometer resistance and proving ring penetrometer resistance. Penetrometer resistance may be a better indicator than soil bulk density of seedling performance in compacted soils (Zisa et al. 1980). Several studies have shown that resistance to a metal probe correlates well with soil resistance to root penetration (Gooderham and Fisher 1975; Sands et al. 1979; Zisa et al. 1980).

Permeability

Because compaction alters soil porosity, it can be assessed by the ability of a liquid or air to pass through the pore spaces. An increase in bulk density generally lowers macroporosity (the number of macropores, or noncapillary pores through which water and gas usually flows rapidly) and reduces permeability (Howard and Singer 1981).

In liquid permeability tests, a known amount of fluid (e.g., water) is applied to a soil core or surface and its infiltration rate assessed. However, liquid permeability measurements are not easily made and can be time consuming. Although a strong laboratory relationship has been shown between fluid conductivity and compaction variables, insufficient field testing increases the difficulty in assessing the operational usefulness and accuracy of such a test (Freitag 1971).

In air permeability tests, a known pressure of gas is applied to the soil surface and the backpressure measured (in pounds per square inch, or kilopascals). Air permeability tests are relatively quick and easy and only minimally disturb the soil. However, because the test apparatus must be sealed against air losses, the contact zone between soil and test instrument must be sufficiently leakproof. Moreover, the optimum condition for such tests is a perfectly dry soil (e.g., dry sand) because the presence of water in pore spaces complicates the evaluation of test results: a soil with different water-retention abilities can be expected to produce different air permeameter measurements (Freitag 1971; Gifford et al. 1977). Unfortunately, the optimum dry condition is not usually attained in practice, so the resulting values must be appropriately calibrated (Freitag 1971; Adams 1983).

Visual Observations

Of all techniques for assessing soil compaction, visual observations may be the most rapid and least expensive. Visual evidence includes reduced

drainage because of reduced soil permeability, difficulty in penetrating the soil surface (e.g., with a shovel) especially when dry, soil structure changes (e.g., a compacted soil when dry will be brittle and often layered, a noncompacted soil crumbly and granular), and good initial germination followed by stunted plant development later on (Freitag 1971; Adams and Froehlich 1981). However, visual observation is difficult to use in monitoring less than severe compaction levels and, of all techniques, is the most subjective and least quantitative (Adams 1983).

RELATIONSHIPS BETWEEN SOIL FACTORS AND COMPACTION

A compacted soil reflects conditions of increasing bulk density and soil strength, and decreasing porosity and infiltration. Most of the loss in porosity is in the macropores, where air and water movement is normally the least restricted (Greacen and Sands 1980; Adams and Froehlich 1981; Warkentin 1984). However, the degree to which compaction affects soil properties will be influenced by texture, organic matter, and soil moisture.

Texture

Texture refers to the relative proportions of sand, silt, and clay in a particular soil. Grain-size distribution and composition affect the resistance of soil to compaction. Soils with a narrow range of grain sizes resist compaction reasonably well, but soils with a wide range of grain sizes are more susceptible because the smaller grains move into the pore spaces between the larger grains, thereby increasing the packing of soil particles (Lull 1959; Bodman and Constantin 1965; Warkentin 1971; Froehlich 1974).

Organic Matter

Soil resistance to compaction is significantly influenced by organic matter content (Greacen and Sands 1980). Organic matter stabilizes aggregates and alters aggregate strength (Warkentin 1984).

Benefits of organic matter have been observed in both laboratory and field tests. Estimates of bulk density (0.54 to 0.63 g/cm^3) in the surface 20 cm of soil of an old plank road were found to be low because of high organic matter content (Power 1974). Sands et al. (1979) reported that the degree of soil compaction changed with differences in organic matter content under a given constant applied load, bulk density generally decreasing with increasing organic matter content under unsaturated conditions. Yet extremely high levels of organic matter may render soils susceptible to disturbance because of their low soil strength (Froehlich and McNabb 1983).

Soil Moisture

The most significant factor influencing soil compaction is moisture level during the compaction process (Warkentin 1984). In general, resistance to compaction is large when soils are dry because little lubrication (for particle rearrangement) is provided by thin water films (Lull 1959). As moisture content increases, lubrication increases and soil becomes easier to compact. For example, Eavis (1972) found that penetrometer resistance decreased as moisture content (at the time of compaction) of a sandy loam increased. In an unsaturated sandy soil, bulk density increased as applied load (range 60 to 360 kPa) increased (Sands et al. 1979); at the lightest load, it was ~ 1.3 g/cm^3, at the heaviest 1.4 g/cm^3. But in a saturated soil, even slight applied loads (60 kPa) resulted in bulk densities > 1.5 g/cm^3.

However, bulk density due to compaction does not continue to increase as water content increases. Instead, a water content is reached at which the maximum number of smaller particles are forced between the coarser grains and the remaining spaces filled with water (Lull 1959; Hatchell et al. 1970). Beyond the water content at which maximum bulk density is attained, compaction decreases and the potential for soil puddling (destruction of soil structure) increases (Lull 1959; Sidle and Drlica 1981; Warkentin 1984); upon drying, such soils can be left highly compacted.

The influence of water content on compaction is also affected by soil texture. For example, in laboratory tests, sandy clays may be compacted to 1.7 to 2.1 g/cm^3 at only 8- to 15-percent moisture, clays to 1.5 to 1.7 g/cm^3 at 20- to 30-percent moisture (Froehlich 1973). Similarly, Bodman and Constantin (1965) showed that as clay content increased, the percent water content at which maximum bulk density was attained also increased. Warnaars and Eavis (1972) found that penetrometer resistance in fine sands decreased as moisture content increased, but that in coarse sands was relatively unaffected by moisture content. No significant difference in penetrometer resistance at a constant bulk density (1.45 g/cm^3) was found for a sandy soil over moisture contents ranging from 2 to 12 percent (Sands et al. 1979). It is important to emphasize that the previously mentioned results all were from laboratory tests and that, irrespective of the degree of sensitivity to moisture and/or texture, a soil may be susceptible to significant compaction over a wide range of moisture contents in the field (Froehlich and McNabb 1983).

EFFECTS OF COMPACTION ON POROSITY AND DRAINAGE

Porosity

Regardless of the mechanism, the net effect of soil compaction will be reduced air porosity (Grable 1971). Total porosity is defined as the ratio of pore-space volume to total volume (Harris 1971). Of perhaps greater significance than the decrease in total porosity is the change in pore-size distribution. Most of the loss in porosity will be in the macropores, and the proportion of micropores will increase (Harris 1971; Greacen and Sands 1980; Adams 1983; Warkentin 1984). Foil and Ralston (1967) showed that increasing bulk density from laboratory compaction on a loamy sand (1.07 to 1.33 g/cm^3), loam (1.06 to 1.38 g/cm^3), and

clay (1.31 to 1.49 g/cm^3) corresponded to approximately 64- to 69-percent reductions in macroporosity. Under field conditions, vehicular-induced compaction which increased bulk density from 0.90 to 1.20 g/cm^3 reduced macropore volume by 50 percent for a range of forest soils (Hatchell et al. 1970). Campbell et al. (1973) found a 28- to 72-percent decrease in macroporosity in logged areas compared to undisturbed plots, depending on the degree of disturbance.

Drainage

The degree to which compaction affects drainage or infiltration of water is related to the changes in soil structure brought about by the compactive effort. Because compaction generally reduces the proportion of macropores and increases the proportion of micropores, water movement becomes restricted and drainage can be impeded.

Significant relationships have been found among increasing bulk density, decreasing infiltration, and decreasing porosity (Lull 1959). Decreased infiltration rates in compacted soils have been reported after logging (Steinbrenner 1955; Steinbrenner and Gessel 1955b; Perry 1964; Hatchell et al. 1970) and as effects of human and animal traffic (Lull 1959). Reduced infiltration and impeded drainage can lead to surface runoff--excess rain may cause waterlogging and associated aeration problems in the rooting zone (Gifford et al. 1977; Greacen and Sands 1980; Sidle 1980). In addition, compacted soils have low temperatures in spring (Gill 1971) and, because of reduced drainage, remain wet and do not warm as fast as noncompacted (i.e., well-drained) soils.

EFFECTS OF COMPACTION ON SEEDLINGS

The abundance of literature addressing plant responses to changing soil conditions resulting from compaction has not always led to the same conclusions (Lull 1959; Rosenberg 1964; Trouse 1971; Greacen and Sands 1980). The contradictory effects reported are probably due to the complexity of interactions among soil strength, aeration, moisture, nutrient supply, and species. In their review of soil compaction, Greacen and Sands (1980) indicated that of 142 studies they surveyed between 1970 and 1977, 82 percent showed reduced crop yield due to compaction, approximately 8 percent increased yield, 6 percent both reduction and increase, and 4 percent no effect. Of these studies, only 18 percent dealt with tree species, but reduced growth due to compaction has been reported for several economically important tree species including Pinus radiata, Pinus elliottii, Pinus taeda, Pinus ponderosa, Pinus nigra, Picea abies, and Pseudotsuga menziesii.

Seedling Survival

Effects of compaction on seed germination or seedling survival have varied. For Pinus taeda seed sown on a loamy sand, loam, and clay, compaction treatments did not significantly affect germination (Foil and Ralston 1967); however, survival percentages were uniformly reduced on compacted soils, the lowest generally on clay. Likewise, Hatchell (1970) found that over a variety of soil types, a 16-percent average increase in bulk density (1.26 to 1.46 g/cm^3) due to compaction treatments corresponded to a 24-percent decrease in P. taeda seedling establishment; on a clay loam, though, compaction had little effect. For Pinus rigida, Pinus nigra, and Picea abies, Zisa et al. (1980) reported that seedling establishment was generally > 75 percent on a sandy loam, regardless of compaction intensity (1.2, 1.4, 1.6, and 1.8 g/cm^3); on a silt loam, only soil compacted to 1.8 g/cm^3 significantly reduced seedling establishment.

The previously cited results were from greenhouse or shade house experiments. Yet several reports of seedling establishment in areas disturbed or compacted due to logging present similar findings. Steinbrenner and Gessel (1955a) report reduced coniferous seedling establishment for naturally regenerated skid roads compared to cutover tractor-logged areas. Duffy and McClurkin (1974) analyzed several soil characteristics on both failed and successful P. taeda plantations to determine characteristics useful for site classification. Bulk density was the most important: plantation failure was predicted on sites where bulk density exceeded 1.45 g/cm^3. There are, however, several instances in which soil compaction due to skidding or logging has had no effect on conifer survival from the first or second (Youngberg 1959; Campbell et al. 1973) through the fourth (Hatchell 1981) growing season after planting.

Root Growth

Root growth is generally restricted as soils become more compact. For example, Heilman (1981) found that length of primary root penetration of Pseudotsuga menziesii seedlings decreased 71 to 87 percent as bulk density increased from 1.38 to 1.76 g/cm^3 (fig. 1) and that 27- to 30-percent pore space[4] prevented rooting of seedlings 35 to 45 days from germination in loam and sandy loam. Hatchell (1970) showed that for Pinus taeda seedlings growing in a range of soil types, shoot to root ratio (dry weights) after the first growing season was negatively related to macroporosity, suggesting that the proportion of roots increased as air space increased.

The degree to which compaction affects root growth depends on species (Minore et al. 1969; Singer 1981; Halverson and Zisa 1982), soil type (Hatchell 1970; Singer 1981), and magnitude of compactive effort, as well as on environmental factors (table 1). Halverson and Zisa (1982), among others, found that of several growth variables measured, root penetration depth (of three conifer species) was the most responsive to compactive effort. Further, whereas effects of compaction on root dry weights have varied (Foil and Ralston 1967; Hatchell 1970; Singer 1981; Tworkoski et al. 1983), reductions in root penetration > 50 percent are repeatedly noted (table 1). Compaction is also likely to alter root distribution in soil. Decreases

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[4] Percent pore space = 100 - (bulk density/particle density) x 100.

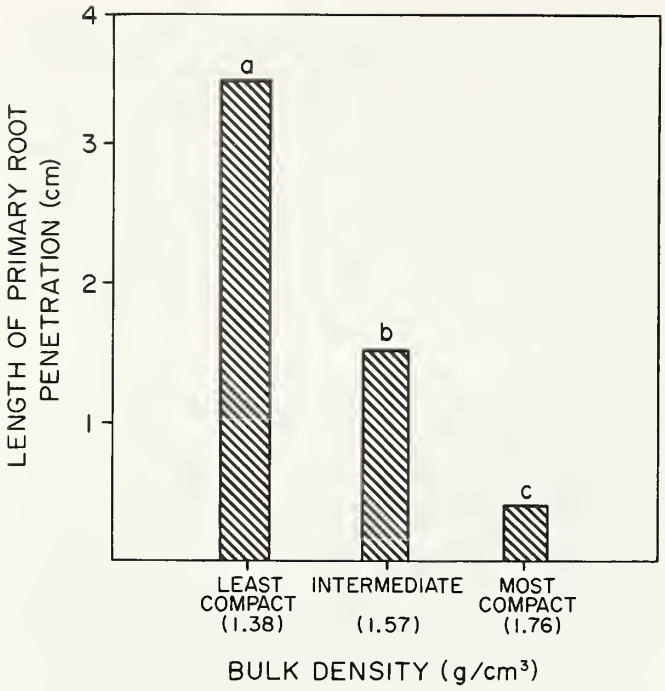

Figure 1.--Length (averaged over three soil types) of primary root penetration of Pseudotsuga menziesii in soils compacted to three bulk densities (adapted from Heilman 1981). Means not followed by the same letter are significantly different at $p \leq 0.05$.

in branching (Pseudotsuga menziesii, Tsuga heterophylla--Pearse 1958), and total root number and fine roots (Pinus ponderosa, Pseudotsuga menziesii--Singer 1981) have been observed for species in compacted soil, although lateral roots (Pinus taeda--Foil and Ralston 1967) and fine roots (Fagus spp.--Hildebrand 1983) have, in some cases, proliferated for trees growing in compacted soils.

In a fine-textured, poorly drained, compacted soil, oxygen deficit can limit root growth; but in a coarse-textured, well-drained compacted soil, or when seedling growth is not limited by lack of water or reduced aeration (Sands and Bowen 1978), reduced root growth or penetration can be related to differences in soil strength (Heilman 1981). Often, however, the factors responsible for poor root growth in compacted soils interact and are difficult to separate. Hatchell (1970) concluded that reduced root growth of Pinus taeda in compacted soils could result from low oxygen supply to roots and high resistance to penetration. Eavis (1972) studied the interaction of mechanical impedance, aeration, and moisture availability for pea growth in a sandy loam soil. Under drier conditions, reduced root growth was due primarily to mechanical resistance if bulk density was high but to moisture stress if bulk density was low. Under wetter conditions, reduced root growth could be due to poor aeration and resistance to penetration in compacted soil but primarily to poor aeration in loose, wet soil.

Shoot Growth

As with root growth, the effect of compaction on shoot growth cannot always be predicted due to the complex interactions among soil physical characteristics and species. If air, water, and nutrients are in sufficient supply and if root length is adequate to meet shoot requirements, poor root development in compacted soils can still support good shoot growth (Hatchell 1970; Greacen and Sands 1980). In some cases, compaction can increase the diffusion of ions (e.g., phosphorus) and improve nutrient uptake; however, under other circumstances, compaction can be detrimental to nutrient status and reduce the mineralization of nutrients from soil organic matter (Kemper et al. 1971; Greacen and Sands 1980). Both large (Forristall and Gessel 1955; Minore et al. 1969) and small (Zisa et al. 1980) effects of compaction on shoot growth have been observed in conifers.

Young (< 2 years) seedling shoot growth varies in response to compaction in laboratory experiments (table 2). Bulk-density increases of 7 to 20 percent have corresponded to reductions of 16 to 56 percent and 11 to 38 percent in shoot dry weight and total height, respectively (Minore et al. 1969; Hatchell 1970; Sands and Bowen 1978). But there are also instances in which increasing compaction has not affected shoot dry weight, shoot growth, or total height (Minore et al. 1969; Heilman 1981; Singer 1981; Tworkoski et al. 1983) or even led to increased shoot growth or shoot dry weight (Trujillo 1976; Singer 1981). These inconsistencies show that compaction effects on young seedlings depend on the interaction of species, age, soil texture, compaction severity, and other soil physical characteristics.

Nearly all field studies relating tree response to compaction have pertained to growth after logging (table 3). In general, tree growth in compacted zones has declined relative to control or undisturbed areas. Estimated reductions in height growth or total height have ranged from 6 to over 50 percent (table 3). Over a variety of tree species, soil types, and field locations, Froehlich and McNabb (1983) found a generally linear relationship between increased soil density and reduced seedling height growth.

THE COMPACTION PROBLEM IN TREE NURSERIES

Despite the concern for soil-related problems, very little research has been done on compaction problems in forest-tree nurseries. Lowerts and Stone (1982) studied the effect of an existing compacted soil layer on nursery growth of Liquidambar styraciflua. After one growing season, seedlings were tallest in nursery plots where bulk densities were < 1.7 g/cm^3 in the surface 39 cm of soil. Furthermore, a significant negative correlation was found between seedling height and bulk density at the 26- ($r = -0.66$), 39- ($r = -0.86$), and 52- ($r = -0.65$) cm depths. Minko (1975) reported of a compacted nursery subsoil (bulk density ~ 1.5 g/cm^3 at the 20- to 40-cm depth) which impeded Pinus radiata tap root penetration. Yet the density (1.2 to 1.4 g/cm^3 in the top 18 cm of soil) of the

Table 1.--Effect on roots as bulk density increased, over a variety of species and soil types, from selected laboratory studies.

Reference	Species [approximate age]	Soil type	Bulk density values	Effect on roots as bulk density increased
			--- (g/cm^3) ---	
Heilman (1981)	*Pseudotsuga menziesii* [35 to 45 days]	Loam, sandy loam	1.38-1.57	54% reduction, length of primary root penetration
			1.38-1.76	87% reduction, length of primary root penetration
Tworkoski et al. (1983)	*Quercus alba* [40 days]	Silt loam	1.0-1.2-1.5	55% reduction, tap root length 59% reduction, primary root number No effect, root dry weight
Pearse (1958)	*Pseudotsuga menziesii*, *Tsuga heterophylla* [56-90 days]	Sandy loam	0.59-0.84-1.02	Shorter, stockier, thicker, not as profusely branched
Zisa et al. (1980)	*Pinus rigida*, *Pinus nigra*, *Picea abies* [120 days]	Silt loam	1.2-1.4	~ 75% reduction, depth of root penetration
			1.2-1.8	~ 80% reduction, depth of root penetration
		Sandy loam	1.2-1.4	No effect, depth of root penetration
			1.2-1.6	~ 50% reduction, depth of root penetration
			1.2-1.8	~ 80% reduction, depth of root penetration
Sands and Bowen (1978)	*Pinus radiata* [150 days]	Sand	1.35-1.48	No effect, main root length or root dry weight
			1.35-1.60	73% and 46% reductions, main root length and root dry weight, respectively
Hatchell (1970)	*Pinus taeda* [150 days]	Loamy sand	1.26-1.46	55% reduction, root dry weight
		Loam	1.30-1.47	40% reduction, root dry weight
		Silt loam	1.34-1.62	50% reduction, root dry weight
		Sandy clay loam	1.14-1.28	29% reduction, root dry weight
		Clay loam	1.04-1.12	17% reduction, root dry weight
Foil and Ralston (1967)	*Pinus taeda* [1 year]	Loamy sand, loam, clay	0.8-1.4	~ 64% reduction, root length[1] ~ 80% reduction, root dry weight[1]
Trujillo (1976)	*Pinus ponderosa* [1 year, 7 months]	Silty clay loam	1.02-1.28	19% increase, root dry weight
Singer (1981)	*Pinus ponderosa*, *Pseudotsuga menziesii* [< 2 years]	Clay loam	0.88-1.10	Uneven root distribution
		Sandy loam	1.06-1.35	Decrease in total root numbers Fine roots decrease No effect, root dry weight for *Pinus ponderosa* 66% reduction, dry root weight for *Pseudotsuga menziesii* on clay loam (no effect on sandy loam)
Minore et al. 1969)	*Abies amabilis*, *Alnus rubra*, *Pinus contorta*, *Pseudotsuga menziesii*, *Thuja plicata*, *Picea sitchensis*, *Tsuga heterophylla* [2 years]	Sandy loam	1.32-1.45-1.59	44% reduction, root dry weight for *Thuja plicata*; no significant effect on other species

[1] Estimates based on regression equation.

cultivated layer was sufficient for root growth; moreover, for two of three nursery blocks, nearly all fine roots were found in the upper soil layer. In addition, some evidence suggested that favorable moisture conditions after early sowing enabled seedling roots to penetrate the compacted subsoil. Recently, an unpublished report[5] showed conditions surprisingly similar to those observed by Minko. In a Northwest conifer nursery, a dense hard layer (bulk density ~ 1.6 g/cm^3) approximately 15 to 30 cm below the surface restricted root penetration of a grass cover crop; the condition was slightly more severe in dry than in moist soil.

Despite the lack of research thus far, the effects of increasing soil density are of special concern to the nursery manager. Compaction may be rare above the 15-cm depth because nursery soils are cultivated each year; however, below 15 cm compaction is relatively common, and is especially noticeable when drainage is impeded for long periods. The machinery used to manage the crop, the ability to control irrigation and fertilization, and the alternatives for tillage are all important aspects of nursery soil management affecting soil compaction.

[5] David K. Maurer, 1983.

PREVENTING AND AMELIORATING COMPACTED SOILS

Maintaining soil in good physical condition, loosening or tilling soil where compacted zones already exist, and controlling vehicular traffic to help avoid compaction must be part of an overall plan to maintain a good physical environment for tree growth in the nursery.

Maintaining Soil Physical Condition

Organic matter can aid soil resistance to compaction; it improves water retention and increases porosity and cation exchange capacity (see Blumenthal and Boyer 1982; review by Davey 1984). Verti-

Table 2.--Effect on shoots of young seedlings (< 2 years) as bulk density increased, over a variety of species and soil types, from selected laboratory studies.

Reference	Species [approximate age]	Soil type	Bulk density values	Effect on shoots as bulk density increased
			--- (g/cm^3) ---	
Heilman (1981)	Pseudotsuga menziesii [35 to 45 days]	Sandy loam, loam	1.38-1.57-1.76	No effect, total height
Tworkoski et al. (1983)	Quercus alba [40 days]	Silt loam	1.0-1.2-1.5	No effect, shoot height or dry weight
Sands and Bowen (1978)	Pinus radiata [150 days]	Sand	1.35-1.48	16% and 11% reduction, shoot dry weight and total height, respectively
			1.35-1.60	49% and 38% reduction, shoot dry weight and total height, respectively
Hatchell (1970)	Pinus taeda [150 days]	Loamy sand	1.26-1.46	42% reduction, shoot dry weight
		Loam	1.30-1.47	33% reduction, shoot dry weight
		Silt loam	1.34-1.62	56% reduction, shoot dry weight
		Sandy clay loam	1.14-1.28	56% reduction, shoot dry weight
		Clay loam	1.04-1.12	31% reduction, shoot dry weight
Trujillo (1976)	Pinus ponderosa [1 year, 7 months]	Silty clay loam	1.02-1.28	15% increase, shoot dry weight
Singer (1981)	Pinus ponderosa, Pseudotsuga menziesii [1 year, 10 months]	Clay loam	0.88-0.99-1.10	32% increase, shoot growth for Pinus ponderosa; no effect, Pseudotsuga menziesii
		Sandy loam	1.06-1.16-1.35	No effect, shoot growth
Minore et al. (1969)	Abies amabilis, Alnus rubra, Picea sitchensis, Pinus contorta, Pseudotsuga menziesii, Thuja plicata, Tsuga heterophylla [2 years]	Sandy loam	1.32-1.45-1.59	37% reduction, shoot dry weight for Thuja plicata; no effect, shoot dry weight for other species

cal mulching can improve root access to additional moisture and increase drainage through subsoiled slots (Gill 1971). Improving drainage to decrease water content can minimize soil compaction (Warkentin 1984). Steinhardt and Trafford (1974) showed that subsurface drainage of a wet clay reduced wheel sinkage and lateral compaction from tractor traffic. Rotating crops also is instrumental in maintaing good soil condition and has long been used to prevent and ameliorate soil compaction (Larson and Allmaras 1971).

Tilling Soil

The unfavorable soil conditions created by compaction can often be improved if the soil is loosened. Tillage can improve soil aeration, infiltration, and pore space distribution and lower strength and bulk density. Generally, the beneficial effects of tillage are in the layer of soil disturbance. Voorhees et al. (1978) and Voorhees (1983), for example, showed that fall plowing was effective in ameliorating compaction from wheel traffic but that bulk density was reduced primarily in the plow layer. Compacted layers in the subsoil (plow pans) can be created by plowing to the same depth crop after crop; and the compaction zone below plow depth has been shown to persist for up to 9 years (Blake et al. 1976). However, not all compacted soils respond favorably to tillage. For example, nutrients may become deficient after deep plowing because topsoils generally contain more

Table 3.--Effect on tree height as bulk density increased in disturbed areas (skid trails, roads, logged), over a variety of species and soil types, from selected field studies.

Reference	Species [Age, years]	Soil type	Bulk density values [measurement depth]	Effect on tree height as bulk density increased	Disturbance type
			----- (g/cm^3) -----		
Campbell et al. (1973)	Pinus taeda [1]	Clay loam	1.34-1.51 [surface 10 cm]	No effect, height growth	Skid trail
Hatchell et al. (1970)	Pinus taeda [1]	Sandy loam	0.75-0.92 [surface] 0.75-1.08 [surface]	21% reduction, total height 53% reduction, total height	Skid trail
Youngberg (1959)	Pseudotsuga menziesii [2]	Clay	0.88-0.95[1] [surface 15 cm] 0.88-1.55[1] [surface 15 cm]	22% reduction, height growth 42% reduction, height growth	Skid road, berm
Froehlich (1979b)	Pseudotsuga menziesii [4]	Sandy loam	0.87-0.95 [surface 15-23 cm] 0.87-0.99 [surface 15-23 cm]	11% reduction, height growth 21% reduction, height growth	Skid trail
	Pseudotsuga menziesii [5]	Clay loam	0.92-1.01 [surface 15-23 cm]	11% reduction, height growth	
Hatchell (1981)	Pinus taeda [5]	Silt loam	--	18% reduction, total height on compacted areas	Skid trail
Lockaby and Vidrine (1984)	Pinus taeda [5]	Loam	1.03-1.13 [surface 5 cm] 1.03-1.17 [surface 5 cm]	59% reduction, total height 39% reduction, total height	Primary skid road, deck
Wert and Thomas (1981)	Pseudotsuga menziesii [~ 14-18]	Loam	0.91-0.99 [5 cm] (1.09-1.26, 30 cm) 0.91-0.93 [5 cm] (1.09-1.13, 30 cm)	30% reduction, total height No difference, total height	Skid road
Froehlich (1979b)	Pinus ponderosa [17]	Sand	0.84-1.15 [surface 30 cm] 0.84-1.24 [surface 30 cm]	23% reduction, total height[2] 29% reduction, total height[2]	Skid trail
Froehlich (1979a)	Pinus ponderosa [~ 64]	Sandy clay loam	0.97-1.14 [7 cm] (1.03-1.12, 30 cm)	~ 6 to 12% reduction, growth rate	Usual logging, cattle use

[1] Bulk density values averaged over two plantations.
[2] Estimated effects based on regression equation.

available plant nutrients than subsoils (Burnett and Hauser 1967). In these cases, incorporating fertilizers with tillage (or soon thereafter) could help. Excessive traffic after tillage also should be avoided. Often, soil that is compacted, loosened, then compacted again will be denser after tillage (Cooper 1971). A tradeoff exists between compaction and tillage--although severe compaction can reduce growth, excessive loosening can be costly and can produce a poor environment for root growth (Gill 1971).

Several types of tools are used for tillage in agriculture (see Cooper 1971) and forestry (see Andrus and Froehlich 1983; Froehlich and McNabb 1983; Froehlich 1984). Investigating compacted conditions in skid trails, Andrus and Froehlich (1983) estimated that the portion of compacted soil effectively tilled by three conventional agricultural tools (brush blade, rock ripper, disk harrow) ranged from 20 to 45 percent; yet adding wings to the sides of ripping tines (via a prototype one-winged subsoiler) consistently tilled at least 80 percent of the compacted soil to a depth of ~ 45 cm. Regardless of the specific tool used, however, it is important to understand the soil conditions at the time of tillage and those created after loosening (Gill 1971). Subsoiling,[6] for example, must be performed under relatively dry conditions so that the implement fractures the compacted zone. When soil is too moist, the implement can pass through the dense soil layer with little amelioration. Furthermore, the restorative action must be dictated by soil conditions, not by a standard operation (e.g., using a tool at a fixed setting).

Tillage experiments have shown a wide range of results. Gill (1971) and Burnett and Hauser (1967) cite numerous studies where tillage has improved either root development or crop yield. Yet in some cases, tillage may bring about the desired soil physical changes without altering yield. Water seems critical in determining crop response. When water is not limiting, yields after tillage may not be increased; but where water movement and root development are restricted by compaction, deep plowing has increased crop yields most (Burnett and Hauser 1967). Burnett and Hauser (1967) concluded the primary benefits of deep tillage to be increases in stored water (due to either improved infiltration or change in particle arrangement) or in root proliferation (enabling roots to obtain water). Additionally, they find that the soil physical changes created by tillage are long term if soils are fine textured, the tillage operation is drastic (e.g., large plows), and compacted zones are essentially genetic, but are more short term if soils are medium to coarse textured, the tillage implement is a subsoiler or chisel, and compacted layers are induced by machinery.

The literature on tillage effects on forest species or soils is not as voluminous as that for crop species. Tilling previously compacted forest soils has generally been beneficial (Andrus and Froehlich 1983); over a range of soil and tillage types, increases of 11 to 83 percent in seedling survival and 13 to 73 percent in seedling height growth have been reported. Nursery seedling height of Pinus radiata seedlings grown in ripped areas was 60 percent greater than that in unripped areas (Minko 1975). Yet Hatchell (1970) found that loosening treatments of compacted soil cores from a range of soil types did not significantly increase either root or shoot dry weight of Pinus taeda seedlings after one growing season, and Warkentin (1984) warned that despite the benefits claimed by nursery managers, the effects of ripping may be only temporary.

Managing Traffic

Intensive management requires the judicious use of machinery to minimize compaction. The following recommendations are from Lull (1959), Gill (1971), Greacen and Sands (1980), Adams and Froehlich (1981), and Warkentin (1984):

Timing operations: If possible, conduct operations on drier soils. Using moisture-based restrictions (especially those based on laboratory tests with unrealistically large forces applied), although sound in theory, is often not practical nor accurate in the field. In addition, delays in field operations due to wet soils increase production costs. Texturally well-graded soils which are low in organic matter may be more susceptible to compaction, so particular care must be taken when traffic is necessary on these sites. Most soils, however, are susceptible to compaction unless already compacted.

Choosing machinery: Modified equipment design (e.g., long-boom sprayers) or use of low-ground-pressure equipment may help minimize the forces applied to soil during operations. Gill (1971) stated that the rear wheel of the agricultural tractor was the worst soil-compacting device used in a crop production system. However, the versatility of the rubber tire probably justifies its use, especially on firm ground. When soils are wet, traction devices such as low-pressure tires may provide an alternative. If load and weight are equal, crawler tractors compact the soil less than wheeled tractors, and surface pressures are reduced further if wider tracks are used. However, a larger area is subject to mechanical vibration with crawler tractors; therefore, estimates comparing ground pressure between crawler and tire tractors may not indicate the entire compactive effect. The use of fixed paths in the nursery also helps prevent compaction in the crop area.

CONCLUSION

Compaction can detrimentally affect soil physical characteristics, resulting in poor tree growth. Yet no one knows whether compaction in forest nurseries is severely inhibiting growth of tree seedlings. However, because of the intensive use of the land required by cultural manipulation of soil and crop, the potential for compaction is a concern shared by most nursery managers. Maintenance of good soil physical conditions, proper

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[6] "Subsoiling" and "ripping" often refer to the same type of tillage treatment, but subsoiling usually is deeper.

tillage, and sound management of vehicle traffic are all important parts of a system to prevent and help ameliorate compacted soils.

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LITERATURE CITED

Adams, P.W. 1983. Recognizing and measuring soil compaction. In Workshop: Forest soil compaction: problems and alternatives. [LaGrande, Oreg., March 22-23, 1983] Department of Forest Engineering, Oregon State University, Corvallis.

Adams, P.W., and H.A. Froehlich. 1981. Compaction of forest soils. Oregon State University Extension Service PNW 217, 13 p. Oregon State University, Corvallis.

Andrus, C.W., and H.A. Froehlich. 1983. An evaluation of four implements used to till compacted forest soils in the Pacific Northwest. Forest Research Laboratory Research Bulletin 45, 12 p. Oregon State University, Corvallis.

Blake, G.R. 1965. Bulk density. p. 374-390. In Methods of soil analysis [C.A. Black, ed.]. American Society of Agronomy, Madison, Wis.

Blake, G.R., W.W. Nelson, and R.R. Allmaras. 1976. Persistence of subsoil compaction in a mollisol. Soil Science Society of America Journal 40:943-948.

Blumenthal, S.G., and D.E. Boyer. 1982. Organic amendments in forest nursery management in the Pacific Northwest. USDA Forest Service Administrative Report, 73 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

Bodman, G.B., and G.K. Constantin. 1965. Influence of particle size distribution in soil compaction. Hilgardia 36:567-591.

Burnett, E., and V.L. Hauser. 1967. Deep tillage and soil-plant-water relationships. p. 49-52. In Proceedings: Tillage for greater crop production. American Society of Agricultural Engineers, St. Joseph, Mich.

Campbell, R.G., J.R. Willis, and J.T. May. 1973. Soil disturbance by logging with rubber-tired skidders. Journal of Soil and Water Conservation 28(5):218-220.

Cooper, A.W. 1971. Effects of tillage on soil compaction. p. 317-364. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

Davey, C.B. 1984. Nursery soil organic matter: management and importance. p. 81-86. In Forest nursery manual: production of bareroot seedlings [M.L. Duryea and T.D. Landis, eds.]. Martinus Nijhoff/Dr W. Junk Publishers, The Hague/Boston/Lancaster for Forest Research Laboratory, Oregon State University, Corvallis.

Day, R.J. 1984. Water management. p. 93-105. In Forest nursery manual: production of bareroot seedlings [M.L. Duryea and T.D. Landis, eds.]. Martinus Nijhoff/Dr W. Junk Publishers, The Hague/Boston/Lancaster for Forest Research Laboratory, Oregon State University, Corvallis.

Duffy, P.D., and D.C. McClurkin. 1974. Difficult eroded planting sites in north Mississippi evaluated by discriminant analysis. Soil Science Society of America Proceedings 38:676-678.

Eavis, B.W. 1972. Soil physical conditions affecting seedling root growth 1. Mechanical impedance, aeration and moisture availability as influenced by bulk density and moisture levels in a sandy loam soil. Plant and Soil 36:613-622.

Flint, A., and S. Childs. 1984. Development and calibration of an irregular hole bulk density sampler. Soil Science Society of America Journal 48:374-378.

Foil, R.R., and C.W. Ralston. 1967. The establishment and growth of loblolly pine seedlings on compacted soils. Soil Science Society of America Proceedings 31:565-568.

Forristall, F.F., and S.P. Gessel. 1955. Soil properties related to forest cover type and productivity on the Lee Forest, Snohomish County, Washington. Soil Science Society of America Proceedings 19:384-389.

Freitag, D.R. 1971. Methods of measuring soil compaction. p. 47-103. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

Froehlich, H.A. 1973. The impact of even-age forest management on physical properties of soils. p. 190-220. In Proceedings: Even-age management symposium [R.K. Hermann and D.P. Lavender, eds.]. [Corvallis, Oreg., August 1, 1972] Oregon State University, Corvallis.

Froehlich, H.A. 1974. Soil compaction: implication for young-growth management. p. 49-64. In Proceedings: Managing young forests in the Douglas-fir region [A. Berg, ed.]. [Corvallis, Oreg., June 14-16, 1972] Oregon State University, Corvallis.

Froehlich, H.A. 1979a. Soil compaction from logging equipment: effects on growth of young ponderosa pine. Journal of Soil and Water Conservation 34(6):276-278.

Froehlich, H.A. 1979b. The effect of soil compaction by logging on forest productivity. Final report to the U.S. Bureau of Land Management for contract 53500-CT4-5(N), 19 p. School of Forestry, Oregon State University, Corvallis.

Froehlich, H.A. 1984. Mechanical amelioration of adverse physical soil conditions in forestry. p. 507-521. In Proceedings: Symposium on site and productivity of fast growing plantations [D.C. Grey, A.P.G. Schonau, and C.J. Schultz, eds.]. [April 30 to May 11, 1984] IUFRO, Pretoria and Pietermaritzburg, South Africa.

Froehlich, H.A., and D.H. McNabb. 1983. Minimizing soil compaction in Pacific Northwest forests. p. 159-192. In Forest soils and treatment impacts. Proceedings: Sixth North American Forest Soils Conference. [Knoxville, Tenn., June 1983] University of Tennessee, Knoxville.

Gifford, G.F., R.H. Faust, and G.B. Coltharp. 1977. Measuring soil compaction on rangeland. Journal of Range Management 30:457-460.

Gill, W.R. 1971. Economic assessment of soil compaction. p. 431-458. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

Gooderham, P.T., and N.M. Fisher. 1975. Experiments to determine the effect of induced soil compaction on soil physical conditions, seedling root growth, and crop yield. Ministry of Agriculture, Fisheries and Food, Technical Bulletin 29:469-480. Wye College, University of London.

Grable, A.R. 1971. Effects of compaction on contact and transmission of air in soils. p. 154-164. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

Greacen, E.L., and R. Sands. 1980. Compaction of forest soils, a review. Australian Journal of Soil Research 18:163-189.

Halverson, H.G., and R.P. Zisa. 1982. Measuring the response of conifer seedlings to soil compaction stress. USDA Forest Service Research Paper NE-509, 6 p. Northeastern Forest Experiment Station, Broomall, Pa.

Harris, W.L. 1971. The soil compaction process. p. 10-44. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

Hatchell, G.E. 1970. Soil compaction and loosening treatments affect loblolly pine growth in pots. USDA Forest Service Research Paper SE-72, 9 p. Southeastern Forest Experiment Station, Asheville, N.C.

Hatchell, G.E. 1981. Site preparation and fertilizer increase pine growth on soils compacted in logging. Southern Journal of Applied Forestry 5(2):79-83.

Hatchell, G.E., C.W. Ralston, and R.R. Foil. 1970. Soil disturbances in logging. Journal of Forestry 68:772-775.

Heilman, P. 1981. Root penetration of Douglas-fir seedlings into compacted soil. Forest Science 27(4):660-666.

Hildebrand, E.E. 1983. Influence of soil compaction on soil functions on forest sites (Inhibitory effect on beech regeneration). Der einfluss der bodenverdichtung auf die bodenfunktionen im forstlichen standort. Forstwissenschaftliches Centralblatt 102(2):111-125.

Howard, R.F., and M.J. Singer. 1981. Measuring forest soil bulk density using irregular hole, paraffin clod, and air permeability. Forest Science 27(2):316-322.

Kemper, W.D., B.A. Stewart, and L.K. Porter. 1971. Effects of compaction on soil nutrient status. p. 178-189. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

Larson, W.E., and R.R. Allmaras. 1971. Management factors and natural forces as related to compaction. p. 367-427. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

Lockaby, B.G., and C.G. Vidrine. 1984. Effect of logging equipment traffic on soil density and growth and survival of young loblolly pine. Southern Journal of Applied Forestry 8(2):109-112.

Lowerts, G.A., and J.M. Stone. 1982. The effect of soil bulk density on nursery sweetgum seedling growth. Tree Planters' Notes 33(3):3-5.

Lull, H.W. 1959. Soil compaction on forest and range lands. USDA Forest Service Miscellaneous Publication 768, 33 p. Washington, DC.

McKibben, E.G. 1971. Introduction. p. 3-6. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

McNabb, D. 1981. Compaction of southwest Oregon soils--shear strength. Oregon State University Extension Service Forestry Intensified Research Report 3(1):3-4. Oregon State University, Corvallis.

Minko, G. 1975. Effects of soil physical properties, irrigation, and fertilization on Pinus radiata seedling development in the Benalla nursery. Forests Commission Victoria Forest Technical Papers 22:19-24.

Minore, D., C.E. Smith, and R.F. Woollard. 1969. Effects of high soil density on seedling root growth of seven northwestern tree species. USDA Forest Service Research Note PNW-112, 6 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

Pearse, P.H. 1958. A study of the effects of soil compaction on the early development of seedlings of Douglas-fir and western hemlock. University of British Columbia Forest Club Research Note 16, 7 p. Vancouver.

Perry, T.O. 1964. Soil compaction and loblolly pine growth. Tree Planters' Notes 67:9.

Power, W.E. 1974. Effects and observations of soil compaction in the Salem District. USDI-BLM Technical Note 256, 12 p. Salem, Oreg.

Rosenberg, N.J. 1964. Responses of plants to the physical effects of soil compaction. Advances in Agronomy 16:181-196.

Sands, R., and G.D. Bowen. 1978. Compaction of sandy soils in radiata pine forests. II. Effects of compaction on root configuration and growth of radiata pine seedlings. Australian Forest Research 8:163-170.

Sands, R., E.L. Greacen, and C.J. Gerard. 1979. Compaction of sandy soils in radiata pine forests. I. A penetrometer study. Australian Journal of Soil Research 17:101-113.

Sidle, R.C. 1980. Impacts of forest practices on surface erosion. Oregon State University Extension Service PNW 195, 15 p. Oregon State University, Corvallis.

Sidle, R.C., and D.M. Drlica. 1981. Soil compaction from logging with a low-ground pressure skidder in the Oregon Coast ranges. Soil Science Society of America Journal 45:1219-1224.

Singer, M.J. 1981. Soil compaction-seedling growth study. Final technical report to the United

States Forest Service Region 5 for cooperative agreement USDA-7USC-2201 supplement 43, 51 p.

Steinbrenner, E.C. 1955. The effect of repeated tractor trips on the physical properties of forest soils. Northwest Science 29:155-159.

Steinbrenner, E.C., and S.P. Gessel. 1955a. Effect of tractor logging on soils and regeneration in the Douglas-fir region of southwestern Washington. Society of American Foresters Proceedings 19:77-80.

Steinbrenner, E.C., and S.P. Gessel. 1955b. The effect of tractor logging on the physical properties of some forest soils in southwestern Washington. Soil Science Society of America Proceedings 19:372-376.

Steinhardt, R., and B.D. Trafford. 1974. Some effects of sub-surface drainage and ploughing on the structure and compactability of a clay soil. Journal of Soil Science 25:138-152.

Trouse, A.C. 1971. Soil conditions as they affect plant establishment, root development, and yield. Present knowledge and need for research. p. 225-240. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

Trujillo, D.P. 1976. Container-grown ponderosa pine seedlings respond to fertilization. USDA Forest Service Research Note RM-319, 3 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Tworkoski, T.J., J.A. Burger, and D.W. Smith. 1983. Soil texture and bulk density affect early growth of white oak seedlings. Tree Planters' Notes 34(2):22-25.

Voorhees, W.B. 1983. Relative effectiveness of tillage and natural forces in alleviating wheel-induced soil compaction. Soil Science Society of America Journal 47:129-133.

Voorhees, W.B., C.G. Senst, and W.W. Nelson. 1978. Compaction and soil structure modification by wheel traffic in the northern Corn Belt. Soil Science Society of America Journal 42:341-349.

Warkentin, B.P. 1971. Effects of compaction on content and transmission of water in soils. p. 126-153. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

Warkentin, B.P. 1984. Physical properties of forest-nursery soils: relation to seedling growth. p. 53-61. In Forest nursery manual: production of bareroot seedlings [M.L. Duryea and T.D. Landis, eds.]. Martinus Nijhoff/Dr W. Junk Publishers, The Hague/Boston/Lancaster, for Forest Research Laboratory, Oregon State University, Corvallis.

Warnaars, B.C., and B.W. Eavis. 1972. Soil physical conditions affecting seedling root growth. II. Mechanical impedance, aeration and moisture availability as influenced by grain-size distribution and moisture content in silica sands. Plant and Soil 36:623-634.

Wert, S., and B.R. Thomas. 1981. Effects of skid roads on diameter, height, and volume growth in Douglas-fir. Soil Science Society of America Journal 45:629-632.

Youngberg, C.T. 1959. The influence of soil conditions, following tractor logging, on the growth of planted Douglas-fir seedlings. Soil Science Society of America Proceedings 23:76-78.

Zisa, R.P., H.G. Halverson, and B.B. Stout. 1980. Establishment and early growth of conifers on compact soils in urban areas. USDA Forest Service Research Paper NE-451, 8 p. Northeastern Forest Experiment Station, Broomall, Pa.

Computer Use in Nursery Management[1]

Jerry Grebasch[2]

Nursery Management is a blend of art and science. The science aspects give us information that is measureable and recordable. This is the area inwhich the computer offers its value. Nursery Managers need not be computer programers, but need to be able to interact with programers. The Iowa State Forest Nursery uses six basic programs that store and retrieve information on seed lots, seedbed inventory, soil status, tree ordering, cultural practices and cost analysis.

For the past 21 years I have managed the State Forest Nursery for the Iowa Conservation Commission. Currently, production is 6 million seedlings. This is divided between conifers, hardwoods, and shrub material. Average order size is slightly over 1,200 seedlings, with between 4,500 to 5,000 orders being processed annually.

We grow trees so that we can meet reforestation needs. In many states, this can vary from large block plantings to states where plantings are relatively small and always mixed with an eye to wildlife habitat. In all cases, the seedlings must grow. There are some nurserymen who feel that their job ends when the seedlings go out the front gate. But many of us understand that we must follow these seedlings into the field and insure that the plantings are successful. We deal with a great number of variables to achieve that goal. The success of the nursery operation depends on the fact that the plants must survive and grow in the field.

I believe that nursery management is both an art and a science. In many instances, both areas affect our management procedures. As an art, we look through nursery beds, touch seedlings, pull seedlings up to look at the roots, feel the soil with our hands to check the moisture content, look with our eyes in terms of the quality and overall condition, and sometimes work from the heart on how we feel our stock is doing. As a science, nursery management requires keeping records and trying to duplicate results over successive periods of time. It's this aspect of the nursery that I'd like to address myself today, the science of record keeping and the use of computers for this monumental task.

The variation of years of experience among this group points to the need for records. Those who have been managing for a long period of time have gained a wealth of knowledge but it is essential that this knowledge be passed on to our successors, so that they too can continue to produce high quality stock. Records and notes can be passed on. I remember when I first started in this business, my teacher and I would go into the field. Various characteristics were brought to my attention for example, picking up a handful of soil to feel the moisture content. At the time, it was difficult for me to sense. Only time and experience helped. We'd go into the cold storage facility, and I'd be asked to feel the condition of the roots. Quite frankly, it was again most difficult for me to experience the same feelings that my teacher experienced. However, when we were able to get into the office and I could look at the records, I could see what the watering schedule was and then go back to the field to look at the condition of the stock. I was better able to begin understanding nursery management.

Tom Landis has asked me to address the question of when to buy a computer? My answer to that is as soon as you possibly can. I know that some are further ahead in programs for record keeping but it's none too soon for all to start recording information. I haven't found a better method of record keeping than the computer. Before the computer, many times I found myself sacrificing the information just because it would take too long to write it down. I remember walking into a nursery office and having the manager show me on the wall, a board which displayed all the cultural practices that were performed on the various nursery beds. What was shown was the desired rate of fertilization and other cultural practices. When I asked what was actually applied, there was no answer. In keeping records the desired as well as the actual results need to be recorded. The computer allows greater flexibility in which to achieve those results. Then when playing Sherlock Holmes, we can refer back to what was actually applied and

1. Paper presented at the Intermountain Nurseryman's Association Meeting, Fort Collins, CO, Aug. 13-15, 1985.

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begin to analyze the reasons for the possible success or failure of that crop. A quick survey suggests that many have written or are in the process of writing their own software programs. The major concern that I have for this entire computer proliferation is that we are repeating what others have done in the past. I think that it is essential that we stop re-inventing the wheel.

For those areas where programs haven't been written, I'd like to discuss some of the possible problems. This comes mainly from the heart, along with much experience. I think the first thing you must do is analyze the person who will be doing the programming. If that person is well grounded in forestry and nursery management you are ahead of the game. If not, as was my experience, you are going to spend alot of time and energy explaining to them what the nursery process is and getting them to understand your needs. One technique I have found quite effective is to literally draw a picture of the end result. Remember, the programs and software are not going to make decisions for you but rather aid you in making decisions; therefore, the data that you are looking at must be in usable form. It must flow and work well with your operations. Secondly, communications is a very important aspect of software development. I spent the first six months working with the programmer just to develop the terminology. One of the greatest frustrations this programmer had were the exceptions that I was willing to tolerate. The human mind is able to assimilate and put into a meaningful form diverse data on which to base decisions. To the contrary, the computer has to deal with each bit of information so that if you're going to have exceptions, they have to be worked into the programming. Of course, exceptions then make the programming job much more difficult.

I believe you must have an understanding of accounting. There's nothing worse than presenting information to the comptroller and not using basic accounting principles. They will dismiss your information so that your work and good intentions go down the drain.

One of the more important aspects of providing information is to present it in logical form. It is important to think through the steps from imputting the data to the final report. These logical steps are necessary in the programming and will prevent headaches in the future. As we were developing one of our programs, things were going very well until I asked if a particular bit of information could be added. The expression on the programmer's face said just the opposite as he said "Yes, certainly we can do just about anything, but we're going to have to go back to square one, because there is not space left in that field to record the data." Forethought in determining your goals will prevent or at least reduce some of the problems.

It is important to have a good working relationship with the people writing the program. Be sure to ask for the cost estimate of the program in general, and specifically for any changes you request. At one point, I requested that $50 of wages be transferred to another area. It was sometime later I learned that the charge for that correction was $300! Since then, I always ask about the difficulty of the correction and the estimated cost.

There are several things that I would do differently. The first item would be to become more knowledgeable about computers and understand the limitations. I do not want to become a computer programmer, but I do want to know what the computer is capable of and then be able to use that information to make management decisions. I certainly feel that we need to develop educational programs that would enable managers to understand the computer. Many times, in seminars or short courses, we are told how to write programs. I don't think that's necessarily what we need. As I mentioned earlier, <u>think out the problem</u>. Don't rush into having something designed without thinking it through very carefully, no matter who is doing the writing. A brief description or flow chart will aid you in the whole process of program development.

There's an area that I'm still very interested in, but because of finances, have been unable to move into it thus far. The nursery is accumulating a great deal of data on growing stock, but there is one more step that needs to be implemented, the use of bar coding. Bar coding our seedling bags would allow us to trace nursery cultural practices back to the individual order. Then we would be able to develop a data base that would allow us to investigate our nursery product after it has left the nursery.

At the present time, the State Forest Nursery has six basic computer programs. First, is our seed lot information. Second, is the nursery bed inventory. Third, nursery soil data. Fourth, tree order system. Fifth, cultural practices records, and sixth, a cost analysis system.

I'd like to first address myself to the seed lot information. This is a small program but very important in two respects. First, to have at your fingertips the seed lot information that you feel important; and secondly, to have a value of your seed inventory. I was interested in some basic information: the species name, seed lot code, moisture content, germination percent, purity percent, seeds per pound, date that it was tested, who tested it, the source purchased from, the seed origin, crop year, elevation, cost per pound, the beginning weight, current weight, and the dollar value of the seed. This program was one I had written myself. I used Datastar as the input format so it provides me with a fill-in-the-blanks screen. Output is generated through Reportstar. I use this primarily for seeding information in order to know what seed we have available, the quantity, germination percent, seeds per pound, location collected, and so forth so that I can then determine which seed lot to use for our current seeding. The next report is used for our

cost accounting people to show current seed on hand and the value of that seed.

The second computer program is our nursery bed inventory. This was a program originally developed by Dr. Ware at Iowa State University, and then modified by Dan Garst to be used on the IBM PC. I do not intend to go into detail on the statistical analysis of this program but rather address how the data is entered into the computer. If any of you are interested in a copy of the thesis, please contact me. As the sample plots are taken, data is collected on sheets right in the field. These sheets are then brought into the office and using a line editor similar to MS DOS Edlin, entered into the computer. The first program is for checking errors. As an example, if you are using total number of seedlings in a plot as well as saleable number of seedlings, had those numbers been accidentally transposed, the information would be flagged and you would be able to go back and correct the data. Other items being checked are consistency of data and the reasonableness of the numbers. If the data stands up, it is then run through the second program. I should have stated earlier that our initial sample is 20 plots per species and age class. The program is run on the basic 20 plots to determine if an additional number of samples is necessary to achieve the desired degree of accuracy. This program will indicate the additional number of plots necessary and the spacing interval. With the additional plots taken and the data recorded, we then are able to run our final report to yield the number of plantable seedlings and the standard error. This is then the basis for our nursery sales.

The third computer program is soil analysis data. We have purchased a Hach Soil Testing System which works very effectively for us. Data is obtained annually on the three major nutrients and seven micro-nutrients, from samples of all sections of the nursery. Of course, if there are any signs of problems, we will take soil samples immediately. The data is then recorded on paper so that it can be entered into the computer. Current data is merged with previous information to provide an historical basis in chronological order. If there is a need, we can provide a printout for the entire nursery or for a particular location in the nursery.

Fourth is the tree order system that currently handles between 4,500 and 5,000 orders, with an undefined capacity. The beginning document is the application that the landowner submits. The data is entered into our computer using a fill-in-the-blanks system which makes data entry easy for the operator. Items that are recorded include: landowner and address, shipping address if it's different from the landowner's location, county where the trees are to be planted, whether it is to be shipped or picked up, and whether sales tax is to be paid. Each species that the landowner is ordering is recorded by code. Also displayed on the screen is current inventory for that species which is then reduced by the amount of that order. On the right hand of the screen, the current billing cost of trees and tax is applicable is shown. A major decision that we made in establishing this program was to allow changes to the order until just prior to shipping. I know that many will disagree, but we felt in order to better serve the public, we wanted to be sensitive to their needs. If a change is to be made, a correction sheet to the order is completed and the information is entered into the computer. The system is interactive so we are able to go into the data base and change whatever the landowner wishes. An invoice can be generated at any time after the order is entered. The invoice includes order number, species requested and available, cost, and due date. The invoice is generated with a due date so that payment not received in time will cancel the order and return the stock to our sales inventory.

A cumulative, alphabetized listing of customers is generated to enable quick cross referencing of the tree order number when a customer calls.

Once the invoice has been mailed and payment received, a credit change program is used to record order number, date of payment, and the amount paid. At the end of each entry session, a printout is generated to indicate the financial transactions of that session. Because of the last minute change capability, a second or third invoice can be issued if necessary. Any over payment reflects the need for a refund.

As shipping time approaches, a bagging list is prepared. The bagging list can be composed of all orders to be shipped, a group of orders to be shipped, a group of orders to be picked up, or a combination of orders. The bagging list is used internally in our shipping office as a means of checking the day's work and identifying the species composition of each order.

The second item generated is a bag label. This is a gummed label that is applied to our shipping bag. It carries the order number, the name and address, and the number of seedlings in each bag. This aids the people who are preparing the orders. The combinations and maximum amount that can fit into a bag change as variations occur in the stock. Corrections can easily be made to the program that generates the labels.

Another item is a report sent to the district forester indicating the landowner, county to be planted, and the make up of the order. This report can be issued throughout the season to inform district foresters of orders received and processed by the nursery. This is helpful in improving communcations between the nursery and the field.

The end of the season sales report shows amount of stock sold, amount shipped, and amount picked up. There is a variety of other information all pertaining to the orders.

The fifth and sixth computer programs are a

combination of cultural practices and cost analysis. They are grouped together because as data is collected on the cultural practices, you can very easily assign the costs to those activities. We have a labor time classification system that is broken down into four areas. The 100 series are miscellaneous activities such as miscellaneous weeding, spraying, and fertilizing. The 200 series are labor that is directly applicable to a species and age class. The 300 series represents what we call cooperation with others in the Conservation Commission, Iowa State University, and the U. S. Forest Service. The 400 series is the seed collection program. We are able to indicate the number of hours spent collecting specific species of seed.

A general classification meets the necessity of identifying and coding a wide variety of supplies and equipment on the nursery. The first part is a code classification for all seeds, fertilizers, shipping bags, etc. Each piece of equipment valued in excess of $2,000 has a series of code numbers assigned to record labor, fuel, mileage, oil, depreciation, parts, and service.

Lastly, there is a series of miscellaneous codes for work that is done in the nursery: garbage collection, natural gas bills, and so forth. All of these costs are coded when being entered.

The nursery has three sources of input data. The time report, titled Weekly Activity Report, is completed by each employee based on half-hour increments. Second input source is the claims for purchases by the nursery. The claim is coded indicating the piece of equipment or general category that it should be charged to. Third input data is materials and amount used, desired rate, and location of area where applied, which are all recorded on paper by the employee doing the work and then entered into the computer once a week. There is a checking program that data can be run against to detect obvious errors. Once all the data is recorded and run through the checking program stream files are permanently updated. The following is a sample of the wide variety of reports which can be derived from this data base. The bed assignment report contains location, age class, species, bedding area, bed and path area, and seed lot code. This report can also be rearranged by species. These reports are very effective for identifying useable beds for fall seeding. The next report is a current inventory of supplies on hand, including the quantity on hand, the date last purchased, quantity last purchased, and the unit price. The equipment report indicates the fuel cost per hour, gallons per hour, labor and depreciation as well as the total operating costs. These reports are invaluable when considering replacements.

There is a report on each employee which gives a break down of hours and dollars spent in each time classification. Thus, one can easily see where employees are being utilized.

The report summarizing the cost of growing seedlings shows both the direct and indirect costs. These reports can be combined to give costs of producing individual species or groups such as conifers, hardwoods, or shrubs, or total figures for the entire nursery.

Cultural practices report shows in chronological order all of the cultural practices such as the time of fertilization, time and amount of spraying, as well as the desired and actual rates of application. This then is an important tool for developing a complete program for growing nursery stock.

There is no doubt that a computer can be a very valuable tool for nursery managers. With careful planning and attention to detail, records can be developed to insure repeated production of high quality stock.

Recent Developments in the Management of Nursery Pests[1]

Whitney S. Cranshaw[2]

Abstract. Insect pest complexes in the intermountain region continue to change rapidly as new pest species are introduced and different plants become favored in landscapes. Among the more serious of the new pest species to become colonized, has been the honeysuckle witches broom aphid which now threatens the future of tartarian types of honeysuckle throughout most of the country. Developments in insect management, however, continue to keep pace with these changing needs. Use of sex pheromone based insect trapping has expanded so that it is now routinely used to monitor flights and associated egg laying periods for several difficult insect control problems. Insecticide technology has also advanced, with greatest current development among synthetic pyrethroids. Also, broader spectrum Bacillus thuringiensis preparations and soap/detergent sprays are offering less hazardous insect control options that are particularly desirable for high population areas. Finally, expanded use of soil applied systemic insecticides has good promise for control of many insect and mite problems. Advantages of these latter treatments are elimination of drift problems, relative ease of application, and generally thorough plant coverage. Limitations include the need for adequate watering, high toxicity, and the potential for direct effects on plant growth.

Several dozen insect and mite species seriously damage woody plants in the intermountain region. Most threatening are the various bark beetles, (Dendroctonus, Ips, Scolytus, etc.), many of which introduce pathogenic fungi into living trees. Borers, primarily clearwing borers, (Sessiidae), are serious pests of certain trees and shrubs and are capable of directly attacking and killing healthy plants. Many other pest species more indirectly affect the overall vigor and health of woody plants. These include insects and mites which suck plant sap (aphids, scale insects, spider mites) and the numerous beetles, caterpillars, and sawflies which are capable of defoliating plants. Among these latter pest species are several which commonly cause serious aesthetic damage to woody plants (e.g. elm leaf beetle, douglas fir tussock moth, pear slug, etc.)

Unfortunately, the status of woody plant pests in the region is not static and many situations have lately changed for the worse. This, in part, is due to changes in plant species used in urban landscaping. For example, honeylocust has been very extensively planted in recent years and this "pest-free" species is developing numerous serious disease, insect, and mite problems.

Also important has been the widespread introduction of new plant pests into the region. This trend has undoubtedly accelerated in recent years with the population influx. Species lists current a decade ago now have to be updated as many "Eastern" species have become established. For example, during 1985 the gypsy moth, viburnum borer (Synanthedon viburni), and a new species of sawfly infesting juniper were first recorded as established along parts of Front Range Colorado.

Also important has been the spread and establishment of "exotic" species. The most important of these recent arrivals to the nursery industry is the honeysuckle witches broom aphid. This aphid seriously threatens the future of tartarian varieties of honeysuckle in the United States. At present, the honeysuckle witches broom aphid heavily damages this commonly planted shrub throughout the mid-West (including Colorado) and its spread into Utah was confirmed in 1985. Management of this insect is discussed in the C.S.U. Service-in-Action Sheet 5.546 (Cranshaw 1985b).

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[1]Paper presented at the Intermountain Nurseryman's Association Meeting, Fort Collins, Colorado, August 13-15, 1985.

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Improvements in insect management have also progressed in many areas to meet these new challenges.

The use of insect sex pheromone traps in insect pest management has expanded greatly in the past decade. In the past, use of these traps has been greatest in detecting the presence of new pest species in an area. For example, gypsy moth movements continue to be monitored with these traps in many areas of the country.

The most useful application of pheromone technology for plant health care professionals is to follow flights of key insects. This can greatly improve the timing of insecticide applications for plant protection, since flights are correlated with egg laying periods. Among the many pheromone traps available at present, those used for tracking clearwing borers (lilac/ash borer, peach tree borer, viburnum borer), leafrolling caterpillars, and certain pine tip moths are most commonly in use in woody plant protection.

Use of pheromones directly for insect control has also been attempted experimentally. Primary strategies involve either mass trap outs (e.g., certain bark beetles) or mating confusion applications. At present, practical uses of these techniques in nursery production have not been demonstrated.

New developments in insecticides have also occurred, although the pace appears to have slowed in recent years. Primary areas of development involve synthetic pyrethroid insecticides, microbial insecticides, and insect growth regulators.

Development is strongest among the synthetic pyrethroid products. Synthetic pyrethroids are chemically derived from the naturally-occurring pyrethrins which are found as fast-acting insecticides in many household aerosol sprays. The synthetic pyrethroids are marked by having extremely high activity, being effective at rates 1/10 - 1/100 of currently used materials. Mammalian toxicity of the synthetic pyrethroids is generally low, particularly when diluted at use rates, although some individuals report irritation by these materials. Most synthetic pyrethroids have a broad spectrum of activity and a few are also effective miticides. Fluvalinate (Mavrik) is the most recent of these materials to get labelling on woody plants, but many other synthetic pyrethroids should be marketed in the next few years.

Microbial insecticide development primarily concerns improvement of Bacillus thuringiensis products. This area has drawn considerable interest among many biotechnology companies. B. thuringiensis products with effectiveness against leaf-feeding beetles (as well as caterpillars) are being tested successfully. The exceptional safety of B. thuringiensis recommends it for use in high population areas.

Highly promising, but still experimental, is the use of insect parasitic nematodes against soil insects. Several nematode species have demonstrated effectiveness for control of black vine weevil larvae. In 1985, C.S.U. trials also conducted nematode applications which demonstrated control of raspberry crown borer and white grubs.

Rediscovery of an "old" insecticide, soaps, and use of detergents is also becoming more widespread. These materials have often proved very effective for controlling many small insects (aphids, psyllids, etc.) and mites. Safety to the user of soaps and detergents is a major factor in their increased use. Although initial control may be less than with standard insecticides, soap/detergent applications often spare many beneficial insect predators and parasites allowing longer term control. The use of these materials is discussed in C.S.U. Service-in-Action Sheet 5.547, Use of Soaps and Detergents for Insect Control in Colorado (Cranshaw 1985a).

Insecticides with systemic activity (i.e., are translocated within the plant) are also an available tool in insect management on woody plants. These insecticides are often particularly useful for control of "hard-to-reach" insects such as aphids. Greatest use has involved systemic insecticides formulated for use as foliar sprays. These include acephate (Orthene), dimethoate (Cygon), and oxydimetonurethyl (Metasystox-R).

Many of these materials, and others, can be used as soil applications. This treatment method has several major advantages which include: elimination of insecticide drift, generally thorough plant coverage, and ease of application. Soil applied systemic insecticides are routinely used for production of many greenhouse and vegetable crops but are underutilized with woody plants.

Trials conducted at C.S.U. during 1984-85 with soil applied systemic insecticides have targeted 3 difficult-to-control insect problems - honeysuckle witches broom aphid, honeylocust pod gall midge, and the pinyon "pitch mass borer" (Dioryctria sp.). Results have been variable and demonstrate the utility and limitations of these soil applications.

Honeysuckle witches broom aphid control has been outstanding with use of Metasystox-R and Cygon applied as soil drenches. Rates of these materials at 1/16 tsp./3 gallon nursery can have given complete control of this insect for over one month. These results are consistent with those achieved by some Denver area tree care professionals in 1985. Plant injury has been observed with higher rates of Cygon and the phytotoxicity potential of this product is a severe limitation to its use.

Control of honeylocust pod gall midge has been highly variable. Granular formulations of Disyston, Furadan, and Temik have repeatedly failed to provide control. Greatest control (80%+

over 2 generations of the insect) has been achieved with liquid emulsions of Metasystox-R. Furadan 4F applied as a liquid emulsion has been intermediate in performance. Adequate watering to allow insecticide uptake has proved to be critically important.

The pinyon pitch mass borer has resisted control by use of soil applied (or injected) systemic insecticide. This insect causes an extreme disruption of the conducting tissue around the feeding site, preventing adequate uptake of the insecticide. Similarly, other insects which destroy the cambium (bark beetles, borers) are often reported to be poorly controlled unless treatments are initiated early in the infestation.

Therefore, the need for adequate water to allow insecticide uptake and poor translocation to disrupted tissues are key limitations for some uses of soil applied systemic insecticides. These insecticides are also translocated in greatest concentration to newest tissues which can prevent adequate control of species found on older wood. Furthermore, many of the insecticides with systemic ability are highly toxic to mammals and must be used in a very cautious manner.

Another aspect of certain systemic insecticides is their ability to affect the growth of the plant. Phytotoxicity can frequently occur from use of organophosphate types of insecticides, particularly Cygon. Carbamate types of insecticides, (Furadan, Temik), frequently exhibit growth regulator activity. On certain vegetable crops, promotion of flowering has been documented from treatment with these products. In 1984 trials on nursery stock at the Colorado State Forest Service Nursery, transitory increases in growth were noted from treatment of two plant species. Five other species were not observed to have any growth response from treatment with carbamate insecticides. Organophosphate insecticides have not been demonstrated to produce any growth rate increases in these plants when pests were absent.

LITERATURE CITED

Cranshaw, W. S. 1985a. Use of soaps and detergents for insect control in Colorado. Colorado State University Extension Service-in-Action Sheet 5.547, 2p.

Cranshaw, W. S. 1985b. Honeysuckle witches broom aphid. Colorado State University Extension Service-in-Action Sheet 5.546, 2 p.

Greenhouse Production of Quaking Aspen Seedlings[1]

Karen E. Burr[2,3]

Abstract.--This paper describes the procedures for greenhouse production of container grown quaking aspen seedlings used at the Colorado State Forest Service Nursery in Fort Collins, Colorado. Topics include; seed collection and sowing, transplanting, thinning, exponential growth, hardening, pruning, grading, and a comparison of spring and winter crop growth rates.

INTRODUCTION

The Colorado State Forest Service Nursery in Fort Collins, CO, began greenhouse production of container grown quaking aspen (Populus tremuloides Michx.) seedlings on an experimental basis in the fall of 1983. Several crops have been grown since that time and many experiments have been conducted to improve the production process. The information presented here is a composite of the knowledge gained from those several crops and experiments, and represents the best methodology for producing quaking aspen seedlings developed thus far by the nursery.

SEED COLLECTION

The Colorado State Forest Service Nursery collects aspen seed rather than purchasing it, because large quantities of seed can be quickly collected from nearby sources in a good seed year. The seed will remain viable for several years when properly cleaned and stored.

Female aspen clones typically produce large quantities of non-dormant seed having 90 percent or greater gremination every 3 to 5 years (U.S. Department of Agriculture, Forest Service 1974). Seed matures late May to mid-June at 2350 m elevation west of Fort Collins and is collected just prior to release. When the capsules can be split open by hand fairly easily along the lines of suture and the seeds within are tan, rather than the pale green color of immature seeds, branches bearing catkins are pruned from selected seed trees and brought indoors. Seed shed and cleaning should be located in a clean, warm room with low relative humidity, low air movement, and minimal other concurrent uses.

The ends of the collected branches are recut and placed in water to keep the leaves from drying. Pieces of dried leaves are very difficult to separate from the seeds during the cleaning process. Supplying water to the branches also permits the capsules to continue developing, and seed release occurs within 7 to 10 days. Procedures for cleaning aspen seed with a series of soil screens have been described by Roe and McCain (1962). Their approach is improved with the use of a canister vacuum cleaner which can both collect the seeds once shed and supply the forced air needed for cleaning.

Seed moisture content is too high at the time of release for successful long-term storage. If the seed is allowed to come to equilibrium with the atmosphere by waiting 1 to 2 days before vacuuming and cleaning, no further drying measures are usually necessary. Seed moisture content of 6 to 8 percent of fresh weight permits 4 to 6 years storage in air tight containers at -18°C (Fechner et al. 1981, Wang 1973). Aspen seed can be maintained with freezer storage much longer than at storage temperatures above freezing (Benson and Harder 1972).

The quality of the seed, whether just collected or retrieved from storage, can be quickly checked. Radicle and hypocotyl elongation are evident in 48 hours from aspen seed sown on moist blotter paper in a covered petri dish at 20°C (McDonough 1979). It is best to determine seed

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[1]Paper presented at the Intermountain Nurseryman's Association Meeting, Fort Collins, Colorado, August 13-15, 1985.

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[3]Acknowledgements: Sincere thanks to Marvin Strachan and James Fischer for providing an invaluable work experience and for their help in conducting this research; to the Rocky Mountain Forest and Range Experiment Station and Dr. Richard Tinus for financial and editorial assistance; and to Drs. Louis Bass and Philip Stanwood, U.S. National Seed Storage Laboratory, for use of seed storage facilities.

quality prior to sowing or storing, as well as to monitor stored seed periodically.

The cost incurred by the Colorado State Forest Service Nursery in 1984 for seed tree selection and monitoring, and seed collection and cleaning, was $2.20 per gram of pure seed. This is based on an hourly wage of $10 and the discontinuing of cleaning when a purity of at least 90 percent is reached. There were 5300 seeds per gram at a moisture content of 8.4 percent in this particular collection, as calculated from two samples of 50 seeds each.

SOWING

The greenhouses at the nursery are fully controlled with fan and pad cooling, overhead irrigation systems through which fertilizer is applied, supplemental CO_2, and intermittent lighting for photoperiod control. A standard greenhouse environment used for growing several species of containerized conifers at the nursery is also used for aspen production (fig. 1).

Aspen seed is sown directly onto dry Forestry Mix (W. R. Grace Co.) in Colorado Styro-Blocks (30, 458 cc cavaties) after the blocks have been machine filled with mix and moved to the greenhouse benches. Sowing is done by hand using a salt shaker with only one hole (1.5 to 2.0 mm diameter) open. An average of five seeds pass through the hole per shake. This sowing rate is based on germination of 85 to 90 percent. The number of empty cavities is too great if an average of 2 to 3 seeds are released because of a wide range in the actual number of seeds released each shake. Seeds can be sown with a salt shaker, one shake per cavity, at the rate of approximately 9000 cavities per hour.

No surface treatment is applied after the seeds are sown, such as the addition of a layer of perlite or grit. Seedling emergence can be inhibited by a sowing depth of only 2 mm (McDonough 1979). The Styro-Blocks are irrigated immediately following sowing with the overhead mist system until soaked through and are then irrigated as needed, typically three times per day, to prevent the surface of the mix from drying during the first 12

SPECIES Quaking Aspen CONTAINER 458 cc OUTPLANTING Spring LOCATION Colorado State Forest Service Nursery, Fort Collins, CO
CROP Spring 1984

SEASON	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March	April
GROWTH STAGE		Germination; Juvenile Growth	Exponential Growth	Bud Set	Natural hardening Caliper growth		Cold hardening		Meet Chilling Requirements			Maintain Dormancy & Hardiness	
DAY TEMP OPTIMUM (°C)		22		20			1					1	
DAY TEMP PERMISSABLE		21--27		15--27			-1--10					-1--15	
NIGHT TEMP OPTIMUM (°C)		22		15			1					1	
NIGHT TEMP PERMISSABLE		21--22		10--18			-1--7					-6--7	
REL HUM OPTIMUM (%)		60		60									
REL HUM PERMISSABLE		50--80		50--80									
DAYLIGHT		75% sunlight (Corrugated fiberglass)		50% sunlight (Shadehouse)									
SUPPLEMENTAL LIGHT		10 watts/ft^2 6% of time at night. No dark period longer than 15 min.		None									
WATER	Frequent, light, surface always wet.	As needed.		Leach with water. Dry to wilting.			As needed with nutrient solution. Water in excess each time.						
FERTILIZER		Complete pH 5.5--6.0 N = 200 ppm P = 100 ppm K = 160 ppm		None			Complete pH 5.5--6.0 N = 60 ppm P = 100 ppm K = 160 ppm						
CO_2 LEVEL		700-800 ppm when vents are closed during daylight hours.		None									
OPERATIONS		Fill, load greenhouse, sow. Transplant Thin		Move to shadehouse.									

Figure 1.--Growing schedule of the spring 1984 crop of quaking aspen seedlings at the Colorado State Forest Service Nursery.

days. After that time, seedlings are irrigated with fertilizer approximately twice per week.

GERMINATION AND TRANSPLANTING

One week after sowing, germination is complete and seedlings are approximately 0.5 cm in height with cotyledons only. Seedlings reach an average height of 1.0 cm (range = 0.8 to 1.3 cm) and the first pair of true leaves is visible at the end of the second week after sowing. Root systems are fibrous and two-thirds the length of the above ground portion of the seedling at this time.

The aspen are transplanted from cavities with excess seedlings to empty cavities during the second week (fig. 2). Seedlings are lifted with the blade of a small knife and placed in a dibble hole in another cavity. An estimated 5 percent of the total cavities sown with a salt shaker require transplants, and much of the time required for transplanting is spent locating empty cavities. Cavities can be examined and the empty ones filled at the rate of 1800 cavities per hour. However, if empty cavities are already identified, transplanting at the rate of 300 seedlings per hour is possible.

Seedlings show no short term ill effects from transplanting, such as wilting, when transplanted at 1 cm tall. Transplanted seedlings (150) and non-transplanted seedlings (150) were monitored until reaching an average height of 51 cm to determine if there were any long term effects of transplanting. Seedlings transplanted at 1 cm tall were not significantly ($p = 0.5$) different in mean height, caliper, or mortality rate than non-transplanted seedlings thinned at 1 cm tall.

	Height cm	Caliper mm	Mortality %
Transplanted seedlings	53	4.1	7.3
Non-transplanted seedlings	49	4.0	5.3
Statistical test	t-test	t-test	Chi^2

Transplanting an entire crop from seed sown in flats is not recommended. Not only is it unnecessary for seedling estalbishment, but because the seedlings grow very fast, it is nearly impossible to transplant large numbers of seedlings before overcrowding in the flats adversely affects seedling morphology.

THINNING

Thinning to one per cavity is done early in the third week after sowing when the seedlings are at a height of 1.0 to 1.5 cm. Because the seedlings double in height, from 1.0 to 2.0 cm,

Figure 2.--Transplanting a quaking aspen seedling two weeks after sowing. Seedling height is 8 mm.

during the third week, they are within this height range for only 3 to 4 days. It is extremely important to thin before the seedlings become taller than 1.5 cm. High seedling density affects seedling morphology very rapidly when seedlings within a cavity begin to compete as they increase in size. Early competition results in accelerated height growth associated with poor caliper development. Seedlings with this spindly form are unable to remain upright after irrigating because of the weight of the water on the foliage. Taller upright seedlings then suppress shorter ones.

When determining how many aspen to sow at any one time, it is better to stagger the sowings than to sow more than can be thinned in a 4-day period. Seedlings can be thinned at the rate of 400 cavities per hour.

EXPONENTIAL GROWTH

Aspen seedlings sown in the greenhouse in spring or summer double in height the second, third, and fourth weeks after sowing, triple in height the fifth week, and then maintain a growth rate of approximately 1.5 cm per day until hardening is begun (fig. 3). Seedlings reach an average height of 45 cm in 8 weeks and average greater than 60 cm tall in 10 weeks. This rate of height growth is approximately twice that reported by others growing quaking aspen seedlings (Fisher and Fancher 1984, Okafo and Hanover 1978) and naturally established seedlings may require 4 years or more to reach an average height of 45 cm (Williams and Johnston 1984).

A major concern during this period of rapid growth is providing enough water to the roots. The leaves shed a great deal of water from the overhead mist system as the canopy closes. Large seedlings in the Styro-Blocks (fig. 4) need to be irrigated 1.5 to 2 hours to completely soak the

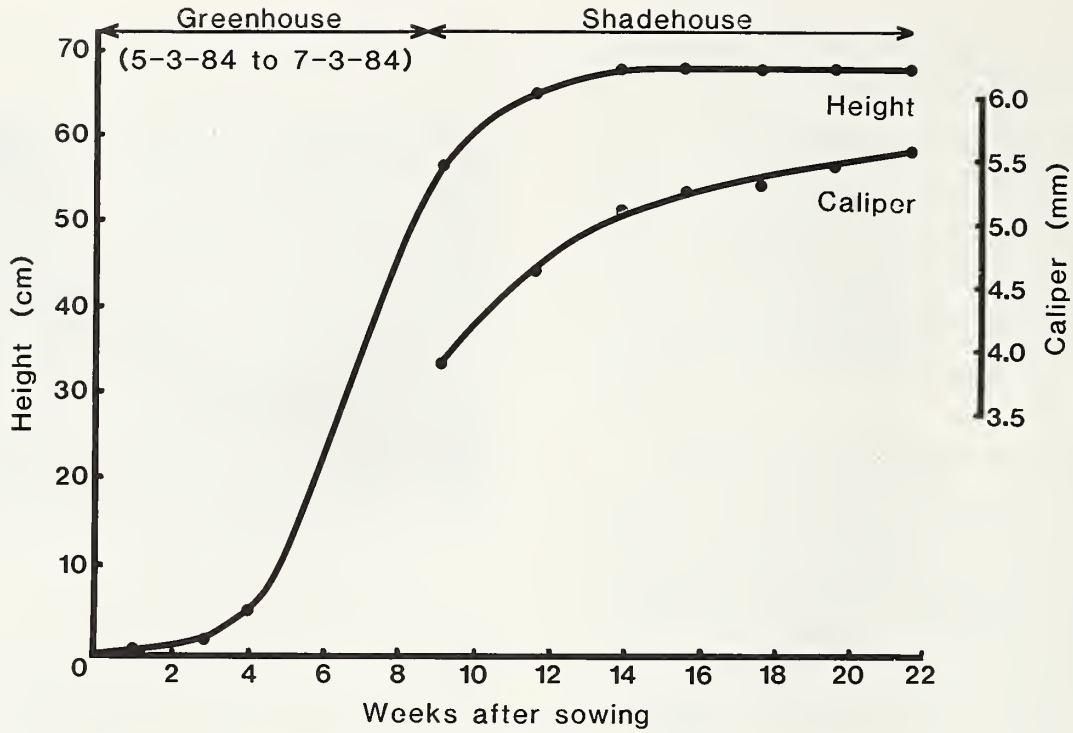

Figure 3.--Height and caliper growth of the spring 1984 crop of quaking aspen sown May 3, 1984. Seedlings were greenhouse grown until July 3, 1984 and then moved to a shadehouse for hardening. The rate of height growth between weeks 5 and 8 is 1.5 cm per day.

the containers. This is 3 to 4 times longer than is necessary prior to canopy closure. If the seedlings are not thoroughly irrigated, shallow root systems develop which can lead to frequent wilting, slowed growth, and the inability to grade seedlings because they cannot be removed from the containers with intact rootballs.

HARDENING

Spring and summer sown greenhouse crops are hardened, as well as overwintered, in shadehouses at the nursery. Actively growing aspen must be moved to shadehouses by early August in the Fort Collins area. Crops moved to shadehouses late August do not complete terminal bud development and have high mortality the following spring.

At the start of the hardening period, excess nutrients are leached from the containers and the seedlings are mildly drought stressed. The fertilizer is changed from high N/PK plus micronutrients to low N/PK plus micronutrients. Containers should be kept up off the ground until fall to allow adequate air pruning of the roots. Deer fencing around those areas of the shadehouses storing aspen is also necessary at the nursery.

Height growth of the spring 1984 crop (fig. 3), which was moved to the shadehouse July 3, 1984, stopped after 4 to 5 weeks in the shadehouse. Final mean height was 68 cm. Extensive root system development followed. Caliper growth continued into October at which time the leaves turned color and abscised normally. Mean caliper in

Figure 4.--Quaking aspen seedlings in Colorado Styro-Blocks at the end of the exponential growth phase. Average seedling height is 55 cm.

October was 5.54 mm. Lateral and terminal bud development were excellent. Overwintering mortality was less than 1 percent.

TOP PRUNING

Top pruning at the beginning of the shadehouse hardening period was tested as a means to stop height growth quickly and improve caliper development relative to unpruned seedlings. Results were the opposite. Eighteen Styro-Blocks of seedlings from the spring 1984 crop were pruned 2 days after being moved to the shadehouse (July 5, 1984) for comparison with the rest of the crop (692 unpruned Styro-Blocks). Average height was 57 cm prior to pruning and 27 cm after pruning. Average caliper of both groups was 3.9 mm at the time of pruning. Pruning induced lateral bud break and the pruned seedlings continued to put on top growth 2 weeks longer than the rest of the crop, thus delaying the hardening process. The caliper of the pruned seedlings 21 weeks after sowing (October 1, 1984) averaged 4.6 mm. This was significantly (t-test, $p = .05$) less than the caliper of the rest of the crop which averaged 5.5 mm at that time (fig. 3). If top pruning is necessary to reduce seedling height, it should be done after the seedlings are dormant.

Height reduction is best accomplished by shortening the period of time for accelerated greenhouse growth. The spring 1984 crop (fig. 3) was grown in the greenhouse for 61 days and reached a final average height of 68 cm. A crop sown in the summer of 1984 was grown in the greenhouse for 51 days and reached a final average height of 50 cm (fig. 5). Both crops were shadehouse hardened and had very similar height growth curves for the first 51 days. The 10-day difference in the growing period results in a substantial difference in final height because of the 1.5 cm per day height growth rate during the exponential phase.

GRADING

Grading is most efficiently done in the shadehouse after leaf abscission. The seedlings are easily handled and inspected then and the large majority of the season's root growth has occurred. Three criteria are used in grading. First, the seedling must be healthy. Second, the stem must be straight and upright, and within a fairly broad height range dependent upon the particular crop. Third, the root system must be extensive enough to permit intact removal of the seedling from the Styro-Block. Grading on the basis of caliper is infrequent because seedlings with poor caliper development also usually have poor stem form and inadequate root systems.

The number of seedlings that make grade is approximately 50 percent of the total cavities sown. Mortality is only 5.3 percent at the end

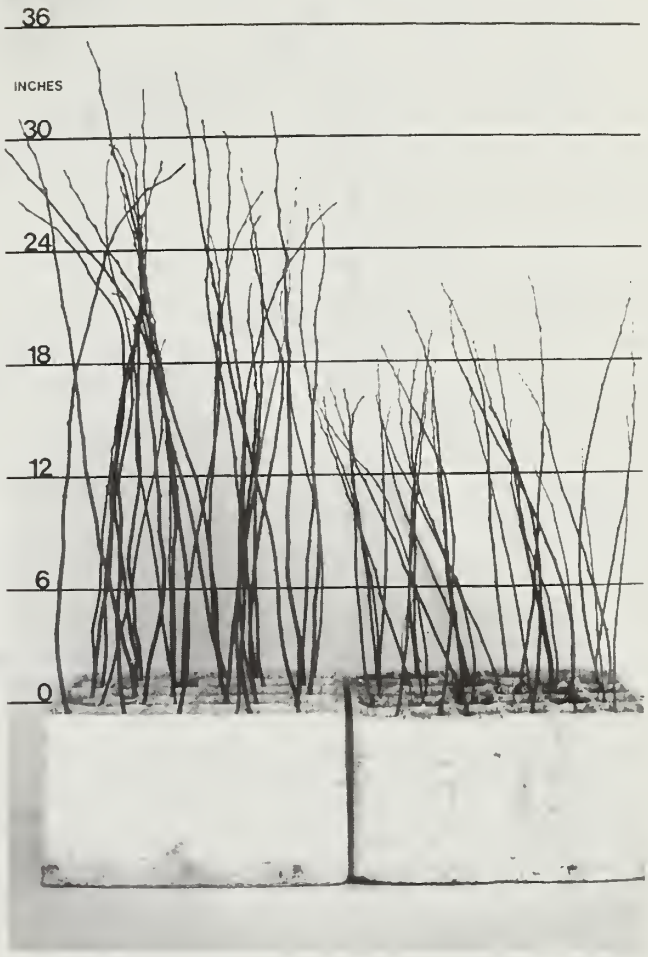

Figure 5.--Graded, dormant quaking aspen seedlings from the spring 1984 crop (left) and a summer 1984 crop (right). The hardening process was begun 61 days after sowing the spring crop and 51 days after sowing the summer crop.

of the exponential phase (see Transplanting tabulation). Thus nearly 45 percent of the cavities sown contain living seedlings at that time which will not make grade. The 45 percent cull rate is the result of seedling variability. To illustrate this, all 30 seedlings in a randomly selected Styro-Block from a crop 2 weeks into the hardening period were measured and ordered by height (fig. 6). Only the tallest 15 seedlings had sufficient caliper to remain upright without support from adjacent seedlings. The next 6 smaller seedlings had poor stem form and were being partially shaded and completely supported by adjacent seedlings. The smallest 9 seedlings, one of which had died (d), were completely shaded by taller seedlings and were growing intertwined among them or on the surface of the Styro-Block. Only the large dominant seedlings make grade at the end of the hardening period.

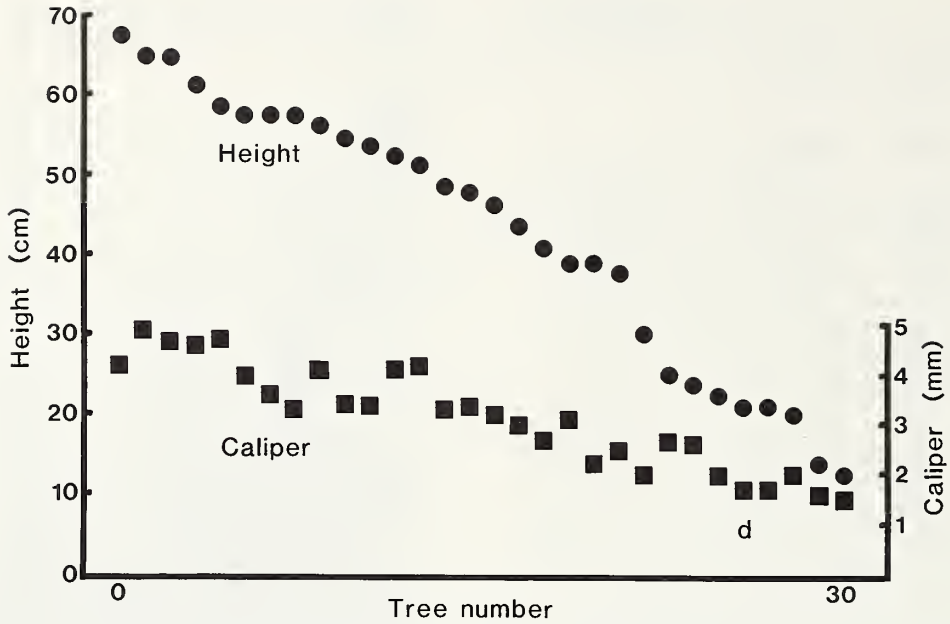

Figure 6.--Variability in seedling height and caliper two weeks into the hardening period within a single Styro-Block of 30 seedlings. One of the 30 was dead (d).

A method for producing a more uniform crop has yet to be developed. Slowing the growth rate by moving established seedlings from the greenhouse to the shadehouse for the majority of the exponential growth phase is being considered. Sorting the seedlings by size when 20 to 30 cm tall to reduce the competition should decrease the cull rate substantially. However, Styro-Blocks, being single 30-cavity units, are not amenable to this, and the seedlings cannot be removed from the blocks with intact rootballs until well into the hardening period.

WINTER CROPS

The growth of winter aspen crops can be as unpredictable as the weather. Growth rates are slower, relative to spring and summer crops, due to the shorter day length and lower light intensities. However, extremely slow rates are possible. The height growth of the winter 1984 crop (fig. 7), sown December 3, 1984, was similar to that of the spring 1984 crop (fig. 2) during the first 3 weeks following sowing. But the exponential growth phases of the two crops are drastically different. Ten weeks after sowing, the winter 1984 crop averaged only 10 cm tall while the spring 1984 crop averaged 60 cm tall. The weather during weeks 3 through 10 of the winter crop was unusually cloudy and the sharp increase in growth after the tenth week was associated with a concurrent improvement in the weather.

Such extreme variability in growth rates can cause scheduling problems. The extension of the time required for the exponential phase can result in a crop of the desired height but for which there is no time remaining for the greenhouse hardening. The uncertainty of winter crops can be avoided without reducing the total number of seedlings produced by growing two crops during the spring and summer months. With a maximum of 8 weeks greenhouse time required per spring crop,

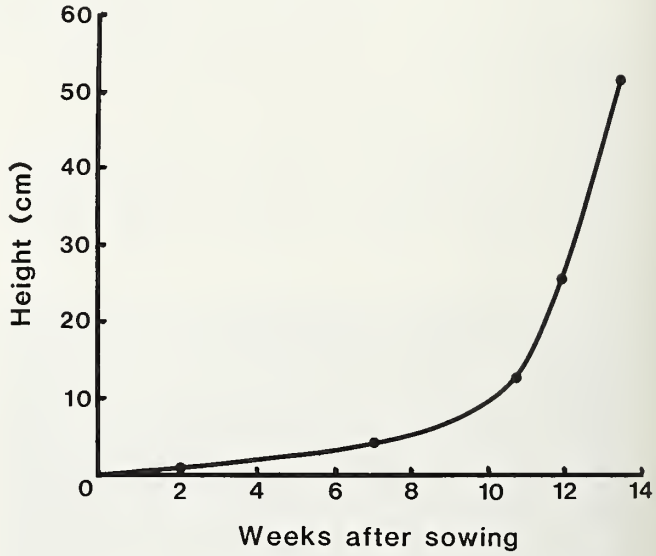

Figure 7.--Height growth, from sowing through the exponential growth phase of the winter 1984 crop of quaking aspen seedlings sown December 3, 1984.

two crops can easily be grown in succession in time to begin shadehouse hardening by August 1.

LITERATURE CITED

Benson, M. K. and M. L. Harder. 1972. Storage of aspen seed. Genet, Physiol. Note No. 11. p. 1-4.

Fechner, G. H., K. E. Burr, and J. F. Myers, 1981. Effects of storage, temperature, and moisture stress on seed germination and early seedling development of trembling aspen. Can. J. For. Res. 11:718-722.

Fisher, J. T. and G. A. Fancher. 1984. Effects of soil amendments on aspen seedling production. In The challenge of producing native plants for the Intermountain area. Proc. Intermountain Nurseryman's Assoc. 1983 conference. Las Vegas, NV. Aug. 8-11, 1983. USDA Forest Service Gen. Tech. Rep. INT-168, 96 p.

McDonough, W. T. 1979. Quaking aspen--seed germination and early seedling growth. USDA Forest Service Res. Pap. INT-234, 13 p.

Okafo, O. A. and J. W. Hanover. 1978. Comparative root and shoot development of trembling and bigtooth aspen seedlings. p. 334-346. In Proc. Fifth North Amer. Forest Biology Workshop, Gainesville, FL. Mar. 13-15, 1978.

Roe, E. I. and D. P. McCain. 1962. A quick method of collecting and cleaning aspen seed. Tree Planters' Notes 51:17-18.

U.S. Department of Agriculture, Forest Service. 1974. Seeds of woody plants in the United States. Agric. Handb. No. 450. Shopmeyer, C. S., tech. coord. Washington, DC. USDA Forest Service, 1974. 883 p.

Wang, B. S. P. 1973. Collecting, processing, and storing tree seed for research use. Proc. IUFRO Int. Symp. Seed Processing. Bergen, Norway. Vol. I. Paper 17.

Williams, B. D. and R. S. Johnston. 1984 Natural establishment of aspen from seed on a phosphate mine dump. J. Range Mgmt. 37:521-522.

Fertilizer Trials on Containerized Red Pine[1]

Kent L. Eggleston[2] and Ruth Crownover Sharp[3]

Abstract.--Nitrate (NO_3), ammonium (NH_4), and urea forms of nitrogen fertilizers were tested on containerized red pine (Pinus resinosa, Ait.) at four locations in Michigan, Wisconsin, and Minnesota. Height, stem caliper, shoot and root dry weight, were all significantly different between treatments. Formulations with both high NO_3 and NH_4 produced larger seedlings at all locations at 14 weeks from sowing. Formulations with just high NH_4 Produced larger seedlings at three locations at 14 weeks old.

INTRODUCTION

Nearly 15 million containerized red pine, Pinus resinosa Ait. seedlings are planted annually on 18 to 20 thousand acres in Minnesota, Wisconsin, and Michigan. The success of these planting efforts depends greatly upon the ability of seedling growers to provide a seedling that will withstand the rigors of the environment.

Seedling growers from forest industry, government, and the private sector gathered in Escanaba, Michigan December 11-12, 1984 to explore ways to improve container stock quality[4]. All agreed that it would be beneficial to produce larger red pine container stock by either maximizing growth during the first 15 weeks in the greenhouse or by culturally controlling shoot height growth.

Red pine exhibits determinate height growth. Generally, 13 to 15 weeks after sowing, red pine seedlings stop shoot height growth and set bud even if environmental conditions are optimum for stem elongation. It is considered beneficial if taller, well balanced containerized seedlings could be produced during the 15-week growth period. Each greenhouse manager attending the Escanaba meeting gave a description of their cultural practices and stock specifications. All locations were similar in operation with only minor cultural practice differences except for one major difference; no two locations used the same fertilizers. A key question discussed was whether nitrate (NO_3), ammonium (NH_4), or urea nitrogen plays a more important role in promoting shoot height growth.

The results of a cooperative study started by growers attending the Escanaba meeting are reported here. The objective of the study was to determine the effects of different nitrogen formulations on the development of containerized red pine seedlings grown under each cooperator's growing conditions. This study was also a pioneering effort to establish a pattern for future cooperative growers trials.

MATERIALS AND METHODS

Cooperators

The cooperating greenhouse facilities included two paper companies, one Federal facility, and one county government contracting with a private facility. The four cooperators and their greenhouse locations were Mead Paper Company, Escanaba, Michigan; Consolidated Paper Company, Monico, Wisconsin; Forestry Sciences Laboratory (FSL), Rhinelander, Wisconsin; and Cass County Land Department, Carlson's Greenhouse in Cass Lake, Minnesota (figure 1).

Container

The seedlings were grown in Styroblock 2-A containers at all locations. This container is a rectangular block of expanded polystyrene containing 240 cone-shaped cavities with a cell density of 103 cavities per square foot. Each cavity is 2.5 cubic inches with a top diameter of 1 inch and a depth of 4.5 inches.

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[1]Paper presented at Intermountain Nurserymen's Association meeting, Fort Collins, Col., August 13-15, 1985.

[2]Kent L. Eggleston, Horticulturist, North Central Forest Experiment Station, St. Paul, Minn.

[3]Ruth Crownover Sharp, Forestry Technician, Ouichita National Forest, Mount Ida, Ark.

[4]Scholtes, John R. Container Grower's Meeting minutes, December 11-12, 1984 in Escanaba, MI. Minutes being assembled at State and Private Forestry, Broomall, Penn.

Figure 1.--Map of Cooperator locations.

Treatment Procedure

Cultural practices for red pine production were identical for all locations except for fertilizer treatments. There were five fertilizer treatments: three standard fertilizers supplied to all locations, and a fertilizer selected by each grower was applied both by hand, and by the grower's production method. The four participating Nurserymen received the same three standard fertilizers, sampling diagrams, mailing bags, and instructions to standardize the three treatments and sampling procedures. The standard fertilizers were measured, mixed in watering cans, and hand applied at all locations. These standards were 20-10-20 (12% NO_3-N, 8% NH_4-N) referred to hereafter as NO_3 (Nitrate), 17-6-6 (17% NH_4-N) referred to hereafter as NH_4 (Ammonium), and 20-19-18 (5.2% NO_3-N, 3.75% NH_4-N, 11.75% urea) referred hereafter as urea (table 1).

In addition, each grower also applied his own in-house fertilizer mix to selected container blocks by hand (treatment designated T-1) and also to the rest of the greenhouse, including three more selected blocks through the production injector-irrigation system (treatment designated T-2). T-1 and T-2 application rates were determined by each grower to simplify his particular stock nutrition needs. growers were encouraged to keep the total N of their selected treatments close to that used for the three standard fertilizers to achieve the best comparison.

When the production stock, including the three selected T-2 treatment blocks, were being fertilized the other treatment blocks were either removed from the area or shielded. After fertilizing all seedlings were rinsed during the water-only portion of the fertilization-irrigation routine.

Each grower determined when to water and fertilize. Some used every-other-day fertilizer schedules. Others established their schedules by monitoring seedling needs and applying when necessary, usually during the exponential growth stage which was from approximately 6 weeks to 14 weeks after sowing. During the first 6-week juvenile growth period, the fertilizer rates were half those shown in Table 1.

Table 1.--Nitrogen constituents in treatments at various locations.

Treatments (by location)	NPK	NO_3	NH_4	Urea	Total N
		ppm			
NO_3[1])	20-10-20	182	122	0	304
NH_4)-all locations	17-6-6	0	258	0	258
urea)	20-19-18	80	57	168	305
FSL T-1, T-2[2]	20-7-19	176	106	21	303
Mead T-1	20-10-20	182	122	0	304
T-2	20-10-20	158	106	0	264
Cass Co. T-1, T-2	10-20-30[3]	77	19	0	96
Combined -------	34-0-0	23	7	0	30
Consol. T-1, T-2	20-20-20	51	36	95	183

[1] NO_3, NH_4, and urea are the standard fertilizer mixes used at all locations.
[2] T-1 and T-2 are the local greenhouse fertilizer treatment applied by hand (T-1) and through the irrigation system (T-2).
[3] 10-20-30 is a nutriculture product, produced by Plant Marvel Laboratories, Chicago, IL. The remaining 5 formulations are Peters soluble fertilizer produced by Grace Horticultural Products Technical Group, Fogelsville, PA.

(Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.)

Experimental Design

At each location, experiment consisted of a randomized block design with three replications. All replications were in the same greenhouse. The T-1, NO_3, NH_4, and urea treatments were each randomly assigned to one styroblock per replication. The three T-2 sample styroblocks were selected from production stock that typified the average stock type of the crop.

Sampling and Data Analysis

A standard sampling design was supplied to each grower for selecting seedling samples biweekly beginning 4 weeks after sowing. Seedlings from each location were kept separate by treatment and replication. Each location sent the seedlings in the supplied mailers to the Rhinelander FSL to be measured, oven dried, weighed, and recorded. Data from all locations were contained and analyzed by ANOVA. Variables analyzed were height, stem caliper, shoot dry weight, root dry weight, and shoot/root dry weight ratio. Included in the model were effects of location, treatment, time, and three two-way interactions. Effects due to replications and replication interactions were combined into a pooled error term. Significance was tested assuming all effects fixed which allowed using the error mean square as the denominator in all F-tests.

RESULTS

In general, main effects were stronger than interactions although interactions were themselves highly significant. Effects due to treatments were stronger than effects due to location for all variables. The fact that interactions were significant suggests that treatments need to be selected on a site-by-site basis in order to maximize growth. No one treatment at 14 weeks old was best at all locations (figure 2).

All seedling/characteristics showed similar responses to fertilizer treatment (figure 3). For example, the urea treatment at the Cass County location produced the poorest seedlings, in terms of characteristics, measured; the T-2 treatment tended to produce the best seedlings.

Responses at the other locations showed similar patterns for 14-week-old seedlings (table 2).

Comparing the standard treatments at the four locations revealed several patterns (figure 4). urea produced the shortest shoots and smallest stem calipers (except for the FSL location). The NH_4 ammonium treatment unexpectedly produced the best seedlings (again, except for shoot height at the FSL location). At three locations, the NH_4 treatment did better than the growers' preferred production treatment, T-2.

DISCUSSION

Some growers learned that other available commercial fertilizers may produce better

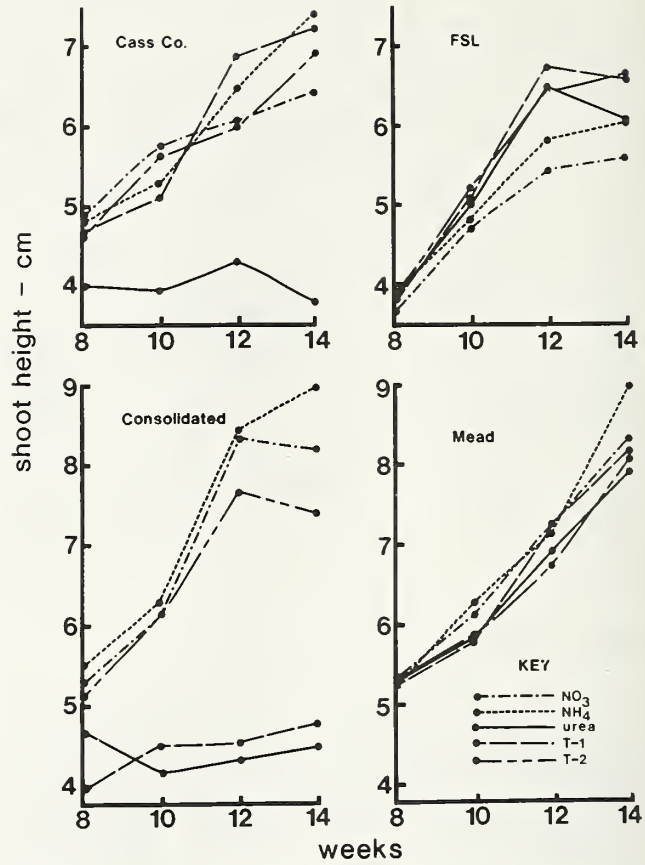

Figure 2.--Containerized red pine shoot height response to fertilizer treatments at various greenhouse locations.

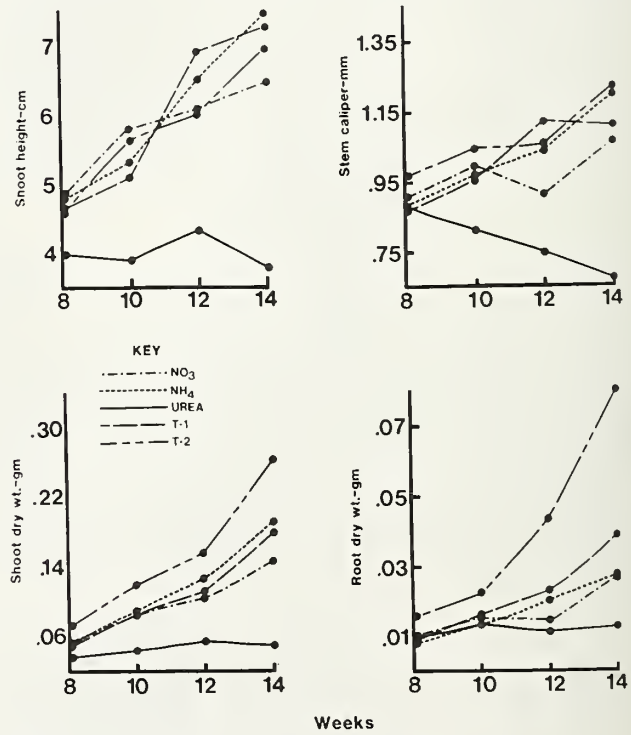

Figure 3.--Containerized red pine physical characteristics by fertilizer treatments at Cass County greenhouse location.

Table 2.--Seedling characteristics at 14 weeks by each location and fertilizer treatment.

	FSL	Mead	Cass County	Consolidated
Stem Height (cm)				
NO_3	5.56	8.28	6.48	8.21
NH_4	6.03	8.90	7.40	9.00
urea	6.06	7.87	3.80	4.50
T-1[1]	6.56	8.08	7.22	4.79
T-2	6.60	8.10	6.90	7.42
Stem Caliper (mm)				
NO_3	1.02	1.30	1.06	1.40
NH_4	1.25	1.37	1.19	1.60
urea	1.19	1.32	0.67	1.02
T-1	1.24	1.38	1.11	0.96
T-2	1.26	1.10	1.21	1.30
Shoot Dry Weight (gm)				
NO_3	.173	.194	.145	.281
NH_4	.295	.206	.188	.356
urea	.252	.180	.048	.106
T-1	.289	.193	.177	.105
T-2	.289	.134	.262	.250
Root Dry Weight (gm)				
NO_3	.046	.058	.026	.101
NH_4	.065	.053	.027	.138
urea	.071	.054	.012	.051
T-1	.074	.057	.038	.044
T-2	.095	.059	.080	.108
Shoot/Root Dry Wt. Ratio				
NO_3	3.8/1	3.3/1	5.6/1	3/1
NH_4	4.5/1	3.9/1	7/1	2.6/1
urea	3.5/1	3.3/1	4/1	2/1
T-1	3.9/1	3.4/1	4.7/1	2.4/1
T-2	3/1	2.3/1	3.3/1	2.3/1

[1]T-1 and T-2 are the local greenhouse fertilizer treatments, hand applied (T-1) and applied same as for greenhouse production (T-2).

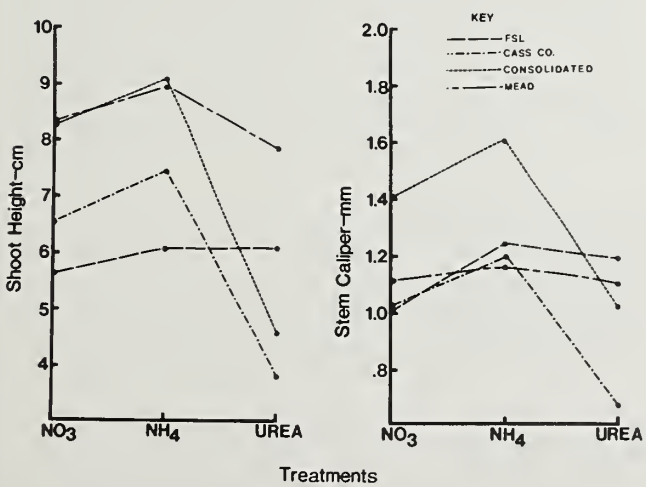

Figure 4.--Fertilizer treatment effects at various greenhouse locations at 14 weeks from sowing.

seedlings than their currently preferred ones. Since three treatments were standard across locations but the treatment responses differed by location, it is clear that fertilizer response depends upon environmental conditioning. To maximize seedling growth, each grower should conduct fertilizer trials periodically to test performance against changes in cultural practices, or to test new fertilizer mixes; an observation worth noting as a grower with multispecie production; the fertilizer treatments that produced better red pine seedlings did not produce better jack pine seedlings. There appears to be specie specific responses to fertilizer that require testing to maximize seedling performances. Results from other growers' trials may not necessarily apply.

The plan for this study, which involved several growers providing data from standard tests with overall coordination provided by a research organization, worked satisfactorily. Thus, the second goal, to develop a pattern for future cooperative trials with area container growers, was achieved.

REFERENCES

Foster, W. J., R. D. Wright, M. M. Alley, and T. H. Yeager. 1983. Ammonium absorption on a pine-bark growing medium. J. Amer. Soc. Hort. Sci. 108(4):548-551.

Gardner, A. C. 1977. A three level nitrogen phosphorous trial to determine optimum fertilizer levels for jack pine container stock. Thesis. Lakehead University, School of Forestry. 16 p.

Lackey, Michelle, and Alvin Alm. 1982/3. Evaluation of growing media for culturing containerized red pine and white spruce. Tree Planters' Notes. 7 p.

Peters Fertilizer Spectometer. 1981. Analysis Manual. W. R. Grace and Company. 138 p.

Phipps, H. M. 1974. Growing media affect size of container-grown red pine. USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN, Research Note NC-165. 4 p.

Van Den Driessche, R. 1971. Response of conifer seedlings to nitrate and ammonium sources of nitrogen. Plant and Soil 34(2): 421-439.

Yeager, T. H., and R. D. Wright. 1982. Does nitrogen outweigh phosphorus in influence on plant growth? American Nurseryman. 2 p.

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Stratification and Germination of Western White Pine Seeds[1]

Rodger Danielson[2]

Abstract.--Techniques of stratifying Western white pine seeds were compared as was length of stratification. Speed of germination increased with increased stratification periods. Layered peat moss stratification and stratification on top of peat/vermiculite substrate were equally effective. Soaking seeds in water prior to layered peat stratification and layering dry seeds produced conflicting results, indicating a need for further study.

INTRODUCTION

Western white pine is an important timber species of the Western United States. Although germination methods have been published in both U.S. and international seed testing rules, the species is very dormant and often firm, ungerminated seeds remain at the conclusion of laboratory germination tests.

Firm seeds are dormant and indicate that pretreatment has not been sufficient to overcome seed dormancy. Even after very lengthly stratification periods, dormancy is not always overcome. Seeds of Western white pine have been reported to germinate in the nursery bed a year after sowing (Kathy Wolfe, 1985, personal communication).

Investigators have begun to look at alternative and more effective methods of pretreating Western white pine seeds. For example, a method utilizing laundry bleach was shown to increase germination and reduce stratification time by 50 percent (Advincula, et al, 1983). A combination of warm and cold stratification was also reported as being effective in overcoming dormancy in Western white pine seeds (Anderson & Wilson, 1966).

J. Herbert Stone Nursery stratification procedures for Western white pine seeds involves soaking seeds in water for 48 hours and then layering the seeds in nylon mesh bags between peat moss at 3C for 13 weeks. They have used this same procedure in their seed laboratory and believe that it gives more rapid germination results than those obtained when following AOSA rules.

This paper is a preliminary report of a cooperative study between J. Herbert Stone Nursery and Oregon State University Seed Laboratory to evaluate the J. Herbert Stone Nursery procedure as a laboratory method for measuring seed germination. It was felt that if stratification procedures between the laboratory and nursery were the same, laboratory results may more closely predict actual field emergence. In addition, it was hoped that speed of emergence would improve, resulting in lower firm seed counts at the conclusion of the germination test.

MATERIAL AND METHODS

Ten seed lots of Western white pine harvested in 1984 from locations throughout Oregon were used in this study. Seeds were tested immediately after extraction and cleaning without any storage period. Germination tests were conducted by placing seeds on media contained within covered plastic boxes measuring 12 cm square x 2.8 cm deep. Each germination treatment consisted of four replicates of 50 seeds. Germination media was a peat/vermiculite mix. Germination temperatures were alternating 20-30C with cool white fluorescent light during the 8 hour 30C period; constant 25C with 16 hours of light daily; and room temperature with 16 hours of light daily. Light at 25C and room temperature was from Sylvania Grow-lux fluorescent tubes. Stratification was conducted by imbibing seeds on top of a peat/vermiculite mix or by layering dry and presoaked seeds between wet Canadian sphagnum peat moss. Seeds that were soaked were placed under running tap water for 48 hours at room temperature. Stratification temperature was 3C. Germination counts were made every 7 days up to 49 days. Remaining ungerminated seeds at the Oregon State University laboratory were cut to determine presence of firm seeds. AOSA Rules for Testing Seeds (1981) were used to evaluate seedlings. Design of the experiment was a split plot.

[1]Paper presented at the Intermountain Nurseryman's Association Meeting, Holiday Inn Convention Center, Fort Collins, Colorado, August 13-15, 1985.

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Table 1.--Percent germination at 28 and 49 days of western white pine seeds stratified on top of and layered between media following soak and no soak treatments. Germination tempertures were 20-30 and 25C. (OSU data)

Sample #	Seeds imbibed on top of peat/vermiculite				Seeds layered between peat			
	20-30C/8 hrs light				25C/16 hrs light			
	No soak				No soak		48 hr soak	
	8 wk ch		13 wk ch		13 wk ch		13 wk ch	
	28	49	28	49	28	49	28	49
3903	3	29	17	59	70	78	83	89
4837	18	49	76	83	41	61	65	79
4838	20	38	52	67	35	50	50	69
4839	29	55	70	79	43	69	65	80
4840	6	42	29	63	22	57	32	55
4841	30	64	63	78	43	79	58	82
6003	30	69	70	85	29	44	54	63
6004	15	54	62	80	26	58	38	59
6005	1	42	13	40	14	24	30	39
6006	-	-	33	67	6	21	29	42
$\bar{X}$	16.9	49.1	48.5	70.1	32.9	54.1	50.4	65.7
$\bar{X}$ Firm seeds*	-	36.7	-	19.3	-	33.4	-	22.4
$\bar{X}$ Viability**	-	85.8	-	89.4	-	87.5	-	88.1

* Firm seed refers to firm ungerminated seed.
** Viability refers to total germination plus firm ungerminated seed.

Table 2.--Percent germination at 28 and 49 days of western white pine seeds stratified layered between peat moss following soak and no soak treatments. Germination temperature was room temperature. (J. Herbert Stone data)

Sample #	Room temperature/16 hrs light			
	No soak 13 wk chill		48 hrs water soak 13 wk chill	
	28	49	28	49
3903	34	77	34	66
4837	61	86	27	64
4838	19	68	39	64
4839	45	73	35	61
4840	7	52	23	48
4841	45	79	31	74
6003	39	73	31	63
6004	16	63	42	74
6005	12	40	13	28
6006	9	32	11	32
$\bar{X}$	28.7	64.3	28.6	57.4

Data was analyzed at the 5% level using both a paired t test and analysis of variance.

RESULTS AND DISCUSSION

Data in Table 1 summarizes Oregon State University results of this study. Total viability, including percent germination plus firm ungerminated seed, remained relatively constant regardless of the treatment. Viability of the seed lots was near 90 percent.

Speed of germination increased with longer stratification periods. Average germination at 28 days was about 17 percent after 8 weeks stratification compared to figures double that after 13 weeks stratification. Speed of germination was not greatly affected by method of stratification. It was felt that stratification in peat moss would increase speed of germination. Only one sample showed a significant response to stratification treatment. Germination percent of sample 3903 was 83 at 28 days when soaked and stratified in peat compared to only 17 percent when seeds were stratified on top of media. One sample showed significantly higher germination at 28 days following stratification on top of media than when soaked and stratified between peat moss. Sample 6004 germinated 62 percent at 28 days following stratification on top of media compared to 38 percent when soaked and stratified between peat moss.

Soaking seeds prior to stratifying between peat increased both speed of germination and total germination on tests at the Oregon State University laboratory, but not at J. Herbert Stone. Average Oregon State University germination results of soaked seeds at 28 days was about 50 percent compared to about 33 percent without soaking (Table 1). Results at J. Herbert Stone (Table 2) were almost identical regardless of treatment. Their average germination percent without soaking prior to stratification between peat moss was 28.7 compared to 28.6 when seeds were soaked prior to stratification between peat moss.

Similar studies are being conducted on the same seed lots after having been in frozen storage for 6 months. To date the results of tests on seeds without storage indicate that speed of germination increases with increased length of stratification. No one method of stratification produced superior results. Stratification procedures used at the Oregon State University Seed Laboratory compared favorable with nursery practices at J. Herbert Stone Nursery. Additional testing will be required to determine whether soaking prior to stratification in layered peat moss influences speed of germination.

LITERATURE CITED

Advincula, B.A. et. al. 1983. A method for germination of Western white pine seeds. Paper presented at Western Forestry & Conservation Association Conference, December 12-14, 1983, Portland, Oregon.

Andersen, H.W. and B.D. Wilson. 1966. Improved stratification procedures for Western white pine seed. State of Washington Department of National Resources Report Number 8.

Association of Official Seed Analysts. 1981. Rules for testing seeds. Journal of Seed Technology 6(2):1-125.

Wolfe, Kathy. 1985. Personal communication. USDA Forest Service, J. Herbert Stone Nursery, Central Point, Oregon.

Development of Underground Cold Storage at Pine Ridge Forest Nursery[1]

J. Roger Hamilton[2]

Abstract.--Three 72 foot (21.6 m) squash culverts were buried under 5 feet (150 cm) of soil at an especially selected site at Pine Ridge Forest Nursery, Alberta, Canada. The culverts were flooded with ice in the winter and provide a passive refrigeration cold storage unit for 2.5 million seedlings.

INTRODUCTION

In 1980, the Alberta Forest Service started a reforestation program called Maintaining Our Forests. The objective of this program was to reforest old burns and convert off site aspen to conifer forests, in order to make up for lands lost to agricultural and petrochemical expansion in Alberta's green zone.

At that time, Pine Ridge Forest Nursery was asked to develope the necessary plans and infrastructure to increase its production from 10 million container seedlings to 20 million and 10 million bareroot seedlings to 18 million.

Part of the increase in bareroot production meant that additional cold storage for bareroot seedlings would be necessary. The conventional cold storage at Pine Ridge Forest Nursery could hold 12.5 million seedlings, leaving a balance of 5.5 million seedlings to be stored or otherwise hot lifted etc.

OBJECTIVES

Several objectives were set for the cold storage addition:

1. The storage structure should hold 2.5 million trees.
2. The storage structure should be built at least cost and have a low maintenance and running cost.
3. This project would be a prototype for field satellite storage.

Figure 1.--Culvert installation at Pine Ridge.

Keeping these objectives in mind, several alternatives were looked at. As a result, snow caches, ice houses and root cellars were investigated. Our forefathers used the concept of root cellars and ice houses for cold storage and preservation for many years, so we thought that a combination of the two concepts would meet all our above-noted objectives. During construction of the seed processing system, the seed cold storage building at Pine Ridge was placed underground. It was discovered that 4 feet (120 cm) underground, providing the surface is never disturbed, the soil had a constant temperature of +39°F (+4°C). Cooling in summer and heating in winter was very inexpensive. Another added feature was the constant temperature of the soil and large masses of soil meant that the temperature would change very slowly if a power failure occurred. Some work had been done in the past with ice in culvert structures, but this was above ground.

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[1]Paper presented at Intermountain Nurserymens Association meeting (Fort Collins, Colorado, August 13, 14-15, 1985).

[2]J. Roger Hamilton is Production Forester, Alberta Energy and Natural Resources, Alberta Forest Service, Pine Ridge Forest Nursery, Smoky Lake, Alberta, Canada.

Putting all of the foregoing together it was decided to bury squash multi plate culverts underground with 5 feet (150 cm) of soil over them. In the dead of winter, the culverts would be flooded until a foot of ice was built-up. Trees would be moved in on pallets on the ice and stored until spring. It was hoped that the ice would last until the end of the shipping season, around the first of July.

A squash culvert design was choosen as the nursery's bareroot boxes can be stacked only six high before the bottom box starts to collapse. Thus height for the ice, pallets and boxes should not exceed 8 feet (2.4 m). Culvert suppliers were consulted and the widest squash culvert of 8 feet (2.4 m) height was 13 feet (3.99 m). This set the width parameter. In order to store 2.5 million trees at 500 trees per box, and using our height and width specifications, a total length of culvert of 216 feet (64.8 m) was derived. It was decided that this length was impractical for a single culvert. The length was divided in three and thus three 72 foot (21.6 m) culverts were installed.

A survey of the nursery site was done at this time, looking for a gulley or depression where these culverts could be installed facing north (shading doors). A suitable site near the north fence was found that had a shaded depression big enough for the three culverts with suitable drainage and allowing for a road to be built for access by a semitrailer truck and 45 foot (13.7 m) reefer van.

Department of Highways bridge branch was consulted, and it was found out that most of these large culverts are bid installed by the manufacturer. Thus tenders for the culverts were let.

CONSTRUCTION

All the excavation work was done using the Nursery's D6 cat. The site had been a dump for waste sand and ash from the nursery clearing. An area 55 feet (16.5 m) by 80 feet (24 m) had to be dug out and levelled. A bed of sand 1 foot (30 cm) thick was laid for each culvert. The bed had to have a very slight grade at 1 percent to provide drainage and was made of sand and/or gravel to prevent the culverts from shifting. At this point, the erection crew came in and installed the culverts. Each culvert was spaced about 8 feet (2.4 m) from the other. Erection took a day per culvert.

Once the culverts had been installed and checked, construction of the back wall commenced. Native pine from the nursery site which was peeled and treated to prevent rot and backed by a 3/4 inch (19 mm) plywood with steel bracing was used for the wall.

Backfilling had to be done very carefully in order to prevent distortion of the culverts. Sand was placed in 6 inch (15 cm) layers and tamped. Layers had to be placed evenly. This had to be done until backfilling was "over the hump" on the sides of the squash culverts. At that point, a large front end loader with a 12 yard bucket was brought in to complete the job until 5 feet (150 cm) of soil covered the culverts.

In the front, three telephone poles were cemented in an upright position between each culvert. Then logs were placed horizontally to form a front wall. Deadman logs were placed between the culverts and cable installed to hold the tops and center of the telephone poles in place.

Double airlock doors were installed, with the inner door having 4 inches (10 cm) of styrofoam for insulation. Air vents were installed in the roof at 1/3, 2/3 and at the end. A manifold was built at the end and a fan used in the winter to increase air circulation during freezing.

Each culvert had a water pipe with spaced nozzles installed in the roof. A water truck is hooked up to the water pipe in the winter and flooding can be completed in a matter of minutes.

The final phase of construction was landscaping the site to channel spring run-off away. A leaching pit was constructed in the roadway by the doors to collect run-off from rain and snow melt. The site was seeded to grass and planted with trees to prevent erosion. The site is to remain undisturbed.

COST

The following is a summary of the costs of building the three culverts:

Culverts and assembly (bid price)	$ 42,233.00
Wages	13,963.00
Materials and supplies	453.00
Administration costs	2,882.00
Equipment operating costs	4,206.00
Total Construction Costs	$ 63,737.00

OPERATION

The culverts were flooded for the first time in the winter of 1983/84. Freezing weather occurred in the first part of November and the doors were opened and a temperature monitor was installed. The first thing that was noticed was that the air temperature did not come down below freezing despite temperatures on the outside that were well below freezing. A circulating fan was installed and cold air blown into the culverts. Slowly the temperature decreased until by early December, ice making could commence. In order to make ice properly, a thin layer of water had to be sprayed over the interior to seal all the cracks before larger amounts of water could be laid on. Even then it was discovered that only a 1/2 inch (1 cm) of water could be flooded on the ice at a

time as thicker layers melted the seal and took a long time to freeze.

By mid January, air temperatures had decreased from +28°F (-2°C) to +25°F (-4°C) and a foot of ice had built-up. The doors were closed and a hydrothermograph probe installed so we could monitor the inside air temperature. Air temperatures were +28°F (-2°C) all winter despite the -40°F (-40°C) outside temperatures experienced.

Toward the spring several hundred boxes of bareroot trees were taken from the conventional cold storage and placed on pallets in the culverts. Temperature probes were installed and the trees were held till spring planting. Temperatures in the box stayed from +28°F (-2°C) to +32°F (0°C) until outplanting. A trial outplanting was conducted in May of 1984, and the trees showed good regeneration potential.

The empty culverts were sealed until mid-summer 1984 when some modifications to the irrigation and air circulation system were made. Even in mid August the culverts still had ice remnants in them.

In November 1984 the culverts were again made ready for use. Ice was slowly built-up over time until a foot of ice was on the floor. In March 1985 all three culverts were loaded up with bareroot from conventional cold storage and extracted containers were added in late March. In box temperatures again remained at +28°F (-2°C) to +32°F (0°C) during storage until spring planting in May.

At the end of shipping, the doors were again closed and the intervening space was filled with bagged vermiculite. It is hoped that ice will be retained year round if proper care is taken to reduce air circulation.

CONCLUSIONS

It appears at this time that all our objectives have been met. An inexpensive, effective cold storage alternative has been proven to be a reality. Tree quality seems to be excellent after storage in this structure. The large mass of soil around the culvert acts as an excellent cold sink in that it is very slow to cool off, and alternately, very slow to warm up. To aid ice making culverts should be sealed when installed. Drainage is important, make sure no water builds up in or around the culvert and prevent the likelyhood of heaving. Our final consolation is the fact that there is some advantages to living in the cold northern latitudes.

LITERATURE CITED

Lawrence, Tomas W. 1980. Eight Foot Diameter Squash Culvert For Seedling Tree Storage. Pamphlet. 10p. No publication data given.

Effects of Ethylene on Development and Field Performance of Loblolly Pine Seedlings[1]

James P. Barnett, Jon D. Johnson,
and Nancy J. Stumpff[2]

Abstract.--Ethylene, a plant growth regulator, was produced by loblolly pine (Pinus taeda L.) seedlings in cold storage. Production was cyclic, with a peak occurring that seemed associated with seedling dormancy. Higher than naturally occurring levels of ethylene stimulated root growth potential, bud activity, survival, and growth. However, the intermediate concentrations that were measured in the cyclic peaks had an inhibiting effect on seedling development and performance. Further research is needed to assess the economical significance of these cyclic concentrations on survival and growth.

INTRODUCTION

Ethylene has long been recognized as a naturally-occurring plant growth regulator that is implicated in a number of important physiological processes (Abeles 1973, Galston and Davies 1970). In amounts as low as a few hundred parts per billion, ethylene can inhibit root growth and bud development and reduce seedling vigor (Kramer and Kozlowski 1979, Wareing and Phillips 1973). Stimulation of ethylene production results from mechanical injury such as occurs during lifting of seedlings from nursery beds (Yang and Pratt 1978).

Few of the effects of ethylene on tree seedlings are known, although this subject has received considerable attention in recent years. Barnett (1981) reported a 75 percent increase in root growth potential of loblolly pine (Pinus taeda L.) seedlings stored for 6 weeks in the presence of an ethylene absorbent. Terminal growth of Fraser fir (Abies fraseri (Pursh) Poir.) seedlings was reduced by 22 percent by exposure to 17.5 ppm of ethylene for 8 weeks in cold storage (Hinesley and Saltveit 1980). Graham and Linderman (1981) found that lateral root growth of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) seedlings was inhibited at ethylene concentrations greater than 150 ppb.

This paper summarizes a series of studies that have evaluated the physiology of ethylene production in loblolly pine seedlings and the effects of ethylene on seedling development and field performance.

METHODOLOGY

The research with loblolly pine by Barnett (1981) was the stimulus for the later series of studies. In this early work with an ethylene absorbent (Purafil ES®)[3] that improved root growth potential and field seedling survival, three replications of seedlings were stored for 3 and 6 weeks in polyethylene bags with and without packets of the absorbent. In response to the positive results from this work, a cooperative effort began with Dr. Jon Johnson of Virginia Polytechnic Institute and State University. In the first of the studies reported by Johnson

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[1]Paper presented at the Intermountain Nurserymen's Association Meeting, Fort Collins, CO, August 13-15, 1985.

[2]Principal Silviculturist, USDA-Forest Service, Alexandria Forestry Center, Pineville, LA; Assistant Professor, Department of Forestry, University of Florida, Gainsville, FL; and Laboratory Technician, Savannah River Ecology Laboratory, Aiken, SC. Johnson and Stumpff were at the Department of Forestry, Virginia Polytechnic Institute, Blacksburg, VA, when the research was conducted.

[3]The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute offical endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

(1983), the atmospheres of two cold storage facilities for seedlings were sampled over a 3-month period during the winter of 1981-82 to determine the extent of ethylene accumulation. Depending upon the location of the facility, biweekly or monthly samples using Vacu-Samplers® were replicated 2 or 4 times. Some sampling of ethylene levels in kraft-polyethylene (K-P) seedling storage bags was also done. The samples were analyzed on a Bendix 2500® gas chromatograph. Complete details of the analysis techniques have been reported (Johnson 1983).

Studies to evaluate the dose-response relationship between ethylene and the performance of loblolly pine seedlings were then conducted. Seedlings lifted late in the season (March) were sealed in K-P bags and exposed to one of six treatments: control, 500 ppb, 1,000 ppb, 2,000 ppb, and 4,000 ppb of ethylene. An additional treatment involved placing a packet of Purafil in the bag with the seedlings. Ethylene concentrations were monitored periodically with gas chromatography, and the concentrations were adjusted as required. The seedlings were stored at 4°C for 6 weeks and then were measured for root growth potential and survival (Johnson and Stumpff 1984b) and for bud activity and first-year heights (Johnson and Stumpff 1984a). The methodology for the estimation of stage of bud development was reported by Johnson and Barnett (1984).

In addition to the evaluation of dose-response relationships, tests were also conducted to determine the effects of lifting date on ethylene production, identify whether ethylene originated in the roots or shoots, and compare the effect of machine versus hand lifting on subsequent ethylene production. Loblolly pine seedlings were lifted monthly from early to late in the season (November to March). Whole seedlings or roots and shoots individually were packaged in K-P bags for 1 week at 3°C. The ethylene concentration within the bags was measured using gas chromatography (Johnson and Stumpff 1985, Stumpff 1984).

RESULTS AND DISCUSSION

Barnett's (1983) data indicated that the presence of an ethylene absorbent greatly increased root growth potential and improved field seedling survival by 6 percentage points, even after three growing seasons (Table 1). No direct measurements of ethylene production were made, but the data suggest that ethylene is produced by loblolly pine seedlings and that it may be, at least partially, responsible for rapid deterioration of seedlings in storage.

Accumulation in cold storage

Johnson (1983) then evaluated the ethylene concentrations in two cold storage facilities and in a limited number of seedling bales and K-P bags. In the storage facility that handled open seedling bales, ethylene concentrations reached

Table 1.--Root growth potential, survival, and heights of loblolly pine seedlings lifted from nursery beds and stored in polyethylene bags with and without Purafil ES[1/] media (from Barnett 1983)

Treatment	Application	Stored 3 weeks			Stored 6 weeks		
		RGP[2]	Survival	Height	RGP[2/]	Survival	Height
		No.of new roots	%	Ft	No.of new roots	%	Ft
Without Purafil ES	1	163	92	5.4	80	84	4.8
	2	133	76	4.8	90	80	4.3
	3	120	88	4.5	84	84	4.9
Average[3/]		139a	85b	4.8 a	85b	83b	4.7a
With Purafil ES media	1	125	92	4.8	158	88	5.2
	2	106	92	4.3	143	88	4.8
	3	159	88	5.2	147	92	4.5
Average[3/]		130a	91a	4.8a	149a	89a	4.9a

[1/] Purafil ES is the trade name of the ethylene absorbent.
[2/] RGP = root growth potential, which is the number of new roots per seedling after 1 month under controlled conditions.
[3/] Means within columns followed by the same letter are not significantly different at the 0.05 probability level for RGP and at the 0.10 probability level for field measurements. Survival and heights reported are those measured after 3 years in the field.

physiologically significant levels (2,300 ppb) in late December (fig. 1). The levels dropped rapidly after this peak was reached, which may have been related to chilling hours or seedling dormancy. Gasoline-powered forklifts were used in this facility and may have added to the ethylene in the atmosphere, but this could not explain the sharp peak in the facility that handled seedling bales. At the other facility, ethylene concentrations remained virtually constant at, or slightly above, the control concentration of 200 ppb. This lack of change was attributed to the use of sealed K-P bags for seedling packaging. Gas samples from within seedling bales and K-P bags indicated that loblolly pine seedlings do produce ethylene.

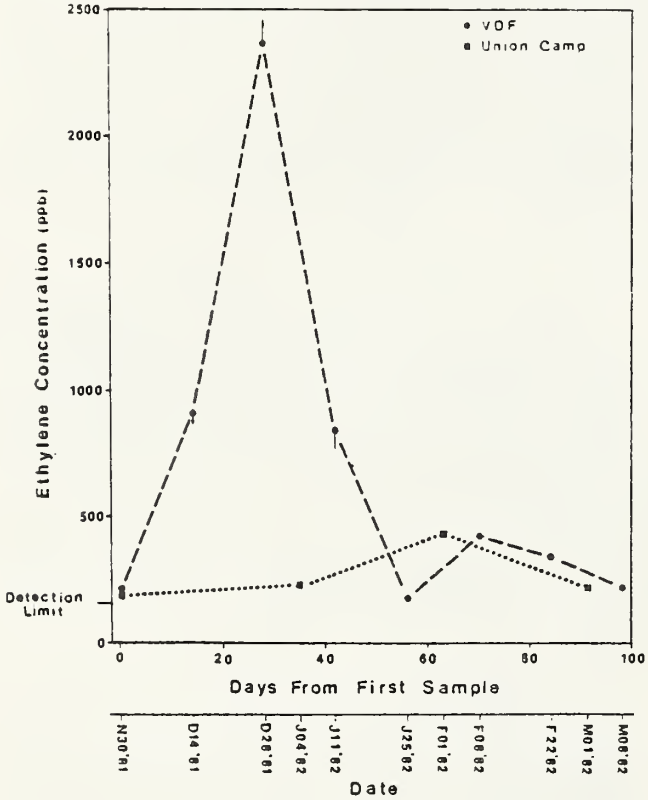

Figure 1.--Ethylene concentration in cold storage facilities of Virginia Division of Forestry and Union Camp during the 1981-82 season. Standard errors are represented by vertical lines where they are larger than the symbols (from Johnson 1983)

Lifting date and method

Evaluations of seedlings lifted monthly from November to March in the following year (1983) and packaged whole or separated into roots or shoots indicated that ethylene production is cyclic, with a maximum concentration occurring in February, perhaps when the chilling hours were met (Johnson and Stumpff 1985). The roots and shoots produced similar quantities of ethylene, about 0.10 ppb/g, except in February when the roots produced about twice as much as the shoots (fig. 2). The significance of this burst of ethylene production is unknown, but it may be associated with the dormancy process. Corroborative data for the involvement of ethylene in bud dormancy comes from a separate study in which bud break was assessed monthly (Johnson and Barnett 1984). In that test, the chilling requirement for bud break was not met until after February 1, 1983. The ethylene peak may correspond with a shift in seedling metabolism from a dormant state of activity in preparation for bud break.

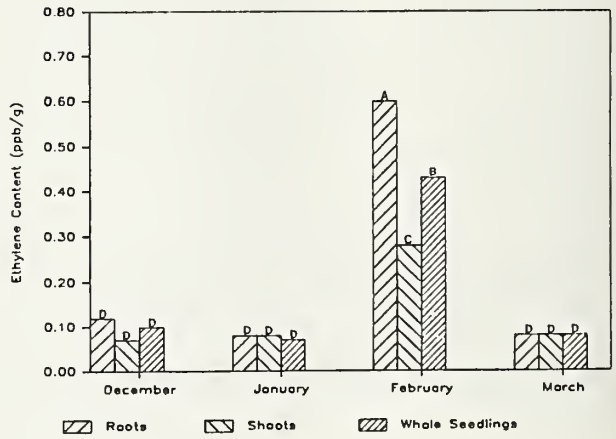

Figure 2.--Ethylene content of K-P bags containing whole seedlings, roots, and shoots of loblolly pine lifted monthly from December to March. Bars with the same letter are not statistically different at the 5 percent probability level (from Johnson and Stumpff 1985)

Lifting method had a significant effect on ethylene production (Johnson and Stumpff 1985). The amount of ethylene produced remained constant for hand lifting between January and March (fig. 3). As a result of machine lifting, however, ethylene content increased from 38 percent in January to 263 percent in March. Machine lifting not only tended to break roots, but the stems of some were compressed by the belts of the lifting machine. The differences in the amounts of ethylene produced between different lifting dates may reflect the change in dormancy status of the seedlings.

Dosage-rate evaluations

Loblolly seedlings lifted in March were exposed to six ethylene treatments (a control, an ethylene absorbent (Purafil ES), and 500, 1,000, 2,000, and 4,000 ppb of ethylene) and stored for 6 weeks before outplanting. The seedlings were eva-

luated for root growth potential, field bud activity, survival, and first-year height growth.

Root growth potential, measured both as cumulative length of new roots and total number of new roots, was significantly affected by ethylene fumigation. The 4,000-ppb and 500-ppb treatments resulted in the greatest root growth potential (Johnson and Stumpff 1984b). The Purafil and control treatments were intermediate, while the 1,000-ppb and 2,000-ppb treatments consistently had the lowest root growth potential.

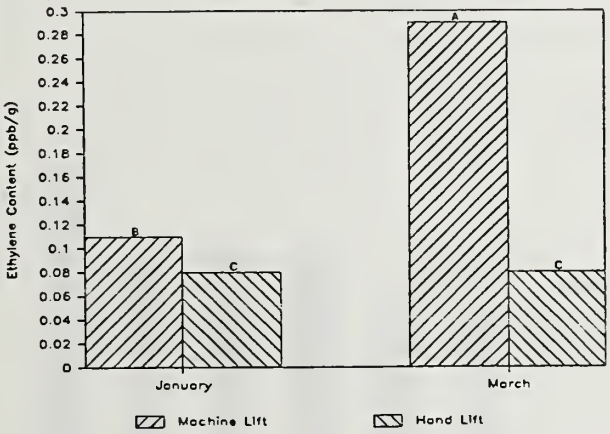

Figure 3.--The effect of lifting method, machine vs. hand, on ethylene content in K-P bags of loblolly pine seedlings lifted in January and March. Bars with the same letter are not statistically different at the 5 percent probability level (from Johnson and Stumpff 1985).

Bud activity assessed 1 month after outplanting by the method of Johnson and Barnett (1984) was significantly affected by the ethylene treatments (Fig. 4). The 4,000-ppb treatment stimulated bud break, but the responses to the other treatments were essentially the same. Spring bud activity as measured here is probably a reflection of root growth; seedlings that initiate early root growth also break bud sooner (Johnson and Barnett 1984, Johnson and Stumpff 1984b). The 4,000-ppb treatment had a positive effect on both root growth and bud break. Zaerr and Lavender (1980) reported a similar response in early-lifted Douglas-fir seedlings exposed to 5,000 ppb of ethylene during 1 month of storage.

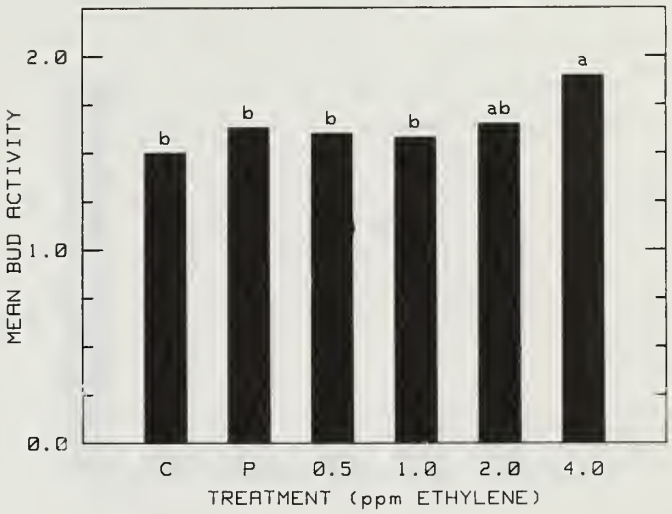

Figure 4.--Mean bud activity 1 month after outplanting of loblolly pine seedlings stored for 6 weeks. Storage treatments were: C - control; P - Purafil; 0.5, 1.0, 2.0, 4.0 - ethylene concentration in parts per million injected and maintained in seedling K-P bags. Bars with the same lower case letter are not statistically different at the 5 percent probability level (from Johnson and Stumpff 1984b). (Explanation of mean bud activity is given in Johnson and Barnett 1984.)

Survival after 1 year in the field was high, ranging from 94 to 99 percent (Fig. 5). Seedlings fumigated with 4,000 ppb of ethylene averaged 99 percent survival, which was higher than all other treatments except the Purafil treatment. The lowest survival was in the 1,000-ppb treatment, which appears to be in the range of concentration measured in the cold storage facilities. However, survival for all treatments was so great that there were no practical differences.

Seedling heights after 1 year in the field were affected by treatment and, again, the 4,000-ppb treatment promoted the greatest response (Fig. 6). All the other ethylene fumigation treatments resulted in similar heights, while the control and Purafil treatments resulted in lower heights.

The results of these studies illustrate that ethylene is physiologically active in loblolly pine seedlings. The responses may be inhibiting or stimulatory, depending upon the dosage to which particular seedling tissue is exposed.

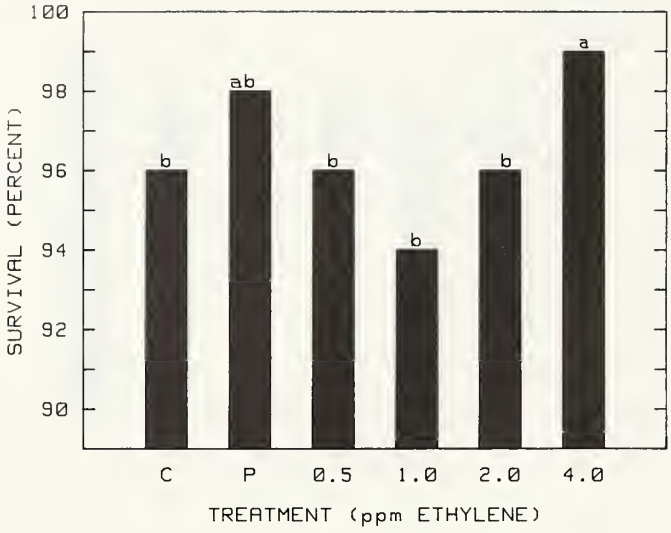

Figure 5.--Survival of loblolly pine seedlings stored 6 weeks after 1 year in the field. (Treatments and statistics are described in figure 4.)

CONCLUSIONS

These results appear to be, at first, conflicting. Ethylene at the 4,000-ppb rate stimulated root growth potential, bud development, survival, and height growth. However, lower concentrations inhibited at least some seedling physiological responses. Abeles (1973) has documented a wide scope of research with other types of plants that demonstrate that ethylene may be inhibiting or stimulating, depending upon concentration.

It is important to note that the 4,000 ppb of ethylene that resulted in positive physiological responses was higher than any level measured under natural conditions in either seedling storage facilities or bags. The 4,000-ppb concentration was also difficult to maintain. Ethylene is a very elusive gas and could not be maintained in sealed K-P bags without repeated fumigation.

Production of ethylene is cyclic, seemingly dependent upon the physiological state of the seedlings. The peaks of production seem closely related to some phase of seedling dormancy. These results must be viewed as an initial attempt to demonstrate the effects of ethylene on seedling survival and growth. Although a reduction in seedling survival due to exposures to ethylene was determined, its overall effect on the performance of loblolly pine seedlings is probably not major. The most practical approach to reducing ethylene concentrations that could affect seedling performance would be to install ethylene-absorbent scrubbers in cold-storage facilities where problems may exist. Further research is needed to assess the economical significance of these cyclic concentrations of ethylene on seedling performance.

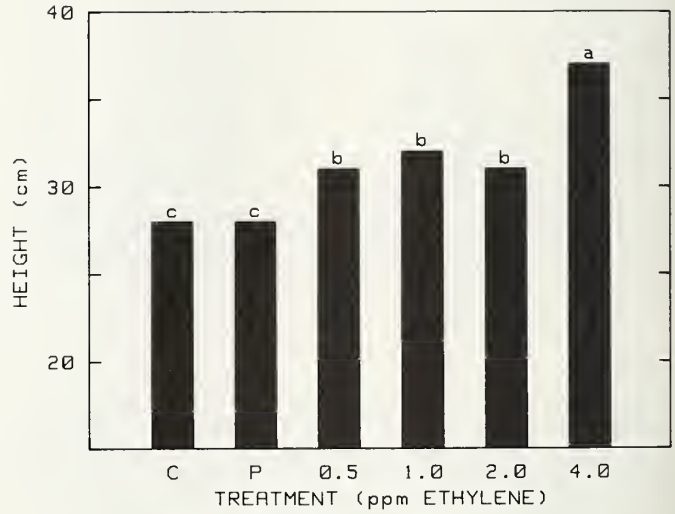

Figure 6.--Heights of loblolly pine seedlings stored 6 weeks after 1 year in the field. (Treatments and statistics are described in figure 4.)

LITERATURE CITED

Abeles, F. B. Ethylene in plant biology. New York, NY: Academic Press; 1973. 302 p.

Barnett, James P. Ethylene absorbent increases storability of loblolly pine seedlings. In: Proceedings, 1980 Southern Nursery Conference; 1980 September 2-4; Lake Barkley, KY; Atlanta, GA: FS Technical Publication SA-TP17. Atlanta, GA: U.S. Department of Agriculture, Forest Service; 1981: 86-88.

Barnett, James P. Ethylene: a problem in seedling storage? Tree Planters' Notes 34(1): 28-29; 1983.

Galston, A. W.; Davies, P. J. Control mechanisms in plant development. New Jersey. Prentice-Hall; 1970. 184 p.

Graham, J. H.; Linderman, R. G.. Effect of ethylene on root growth, ectomycorrhizae formation and Fusarium infection of Douglas-fir. Canadian Journal of Botany 59: 149-155; 1981.

Hinesley, L. E.; Saltveit, M. E. Ethylene adversely affects Fraser fir planting stock in cold storage. Southern Journal of Applied Forestry 4: 188-189; 1980.

Johnson, Jon D. Ethylene accumulation during cold storage of pine seedlings: Is it a problem? In: Proceedings, 1982 Southern Nursery Conferences; 1982 July 12-15; Savannah, GA; 1982 August 9-12; Oklahoma City, OK; Atlanta, GA: FS Technical Publication R8-TP4. Atlanta, GA: U.S. Department of Agriculture, Forest Service; 1983: 224-228.

Johnson, Jon D.; Barnett, James P. Loblolly pine seedling vigor based on bud development. In: Proceedings, 1984 Southern Nursery Conferences; 1984 June 11-14; Alexandria, LA; 1984 July 24-27; Asheville, NC; Atlanta, GA: U.S. Department of Agriculture, Forest Service; 1984: 138-144.

Johnson, Jon D.; Stumpff, Nancy J. Loblolly pine seedling performance is affected by ethylene. In: Proceedings, 1984 Southern Nursery Conferences; 1984 June 11-14; Alexandria, LA; 1984 July 24-27; Asheville, NC; Atlanta, GA: U.S. Department of Agriculture, Forest Service; 1984a: 169-173.

Johnson, Jon D.; Stumpff, Nancy J. The influence of ethylene on root growth capacity and field performance. In: Proceedings, Eighth North American Forest Biology Workshop; 1984 July 30-August 1; Logan, UT. Logan, UT: Utah State University; 1984b: 190.

Johnson, Jon D.; Stumpff, Nancy J. Loblolly pine seedling ethylene production as affected by lifting time and method. In: Proceedings Third Biennial Southern Silvicultural Research Conference; 1984 November 7-8; Atlanta, GA. General Technical Report SO-54. New Orleans, LA: U.S. Department of Agriculture, Forest Service; 1985: 34-37.

Kramer, P. J.; Kozlowski, T. T. Physiology of woody plants. New York, NY: Academic Press; 1979. 811 p.

Stumpff, Nancy J. Ethylene production by loblolly pine seedlings during cold storage and water stress. Blacksburg, VA: Virginia Polytechnic Institute and State University; 1984. 156 p. Thesis.

Wareing, P. F.; Phillips, I.D.J. The control of growth and differentiation in plants. New York, NY: Pergamon Press; 1973. 303 p.

Yang, S. F.; Pratt, H. K. The physiology of ethylene in wounded plant tissues. In: Kadl, G., ed. Biochemistry of wounded plant tissues. New York, NY: Walter de Grayter and Co.; 1978: 595-622.

Zaerr, J. B.; Lavender, D. P. Analysis of plant growth substances in relation to seedling and plant growth. New Zealand Journal of Forest Science 10: 186-195; 1980.

Herbicides for Weed Control in Tree Nurseries[1]

Lyle K. Alspach[2]

Abstract.--Weed control during tree seedling production is of major importance. The Tree Nursery at Indian Head, Saskatchewan, Canada is currently using and testing herbicides to supplement the weed control program. Current uses include: chloroxuron for caragana sowings; chloroxuron or linuron for poplar and willow cuttings; trifluralin for Siberian elm sowings; linuron for choke cherry sowings, conifer transplants and all 1-0 deciduous crops. Promising treatments for future use include: EPTC for caragana sowings, chloramben for honeysuckle sowings, oxyfluorfen for poplar and willow cuttings and conifer sowings and linuron for green ash sowings.

INTRODUCTION

The PFRA Tree Nursery at Indian Head, Saskatchewan, Canada annually produces six to seven million deciduous and coniferous bare root seedlings for distribution to over ten thousand applicants. These seedlings are utilized in field, farm and roadside shelterbelts as well as wildlife and municipal plantings where they reduce wind erosion, provide snow control, food and shelter for wildlife and add aesthetic value.

Good weed control is a major part of seedling production and requires the use of herbicides in addition to the usual manual and mechanical weed control operations. Over the past 25 years the Tree Nursery at Indian Head has been involved in investigative work to establish herbicide practices which can be incorporated into production of bare root tree seedlings.

Major nursery crops at Indian Head include: caragana (*Caragana arborescens*), green ash (*Fraxinus pennsylvanica lanceolata*), willow (*Salix* spp.), poplar (*Populus* spp.), villosa lilac (*Syringa villosa*), Manitoba maple (*Acer negundo*), Siberian elm (*Ulmus pumila*), choke cherry (*Prunus virginiana melanocarpa*), buffaloberry (*Shepherdia argentea*), Colorado spruce (*Picea pungens*), white spruce (*Picea glauca*), and Scots pine (*Pinus sylvestris*).

Herbicides are used during the first year of production for all of the nursery crops listed except green ash, villosa lilac, Manitoba maple and buffaloberry. Work is ongoing for green ash, villosa lilac and honeysuckle (*Lonicera tatarica*) with additional work to evaluate new chemicals for caragana, poplar, willow, and conifers.

Herbicide Treatments Currently Used in Seedling Production

Immediately after sowing caragana, chloroxuron (Tenoran 50 WP) is applied at 5.6 kg/ha. Overhead irrigation provides incorporation. This treatment has generally provided satisfactory results, however, organic matter content of the soil would appear to be a limiting factor as indicated in a 1979 study in which poor control occurred where organic matter content was 5.0 percent and good control was achieved in areas where the soil contained 3.0 percent organic matter. Increased rates of chloroxuron were tested in an attempt to overcome the decreased herbicidal affect caused by adsorption to soils containing higher levels of organic matter. Weed control at 10.0 kg/ha was not significantly better than 6.0 kg/ha, therefore the 6.0 kg/ha rate was retained. Chloroxuron application has no adverse affect on caragana and, in some instances, has actually resulted in increased growth.

Chloroxuron or linuron (Lorox L 48%F or Afolan F 45%F) are used during the production of rooted poplar and willow hardwood cuttings. Investigative trials indicated that linuron at 2.2 kg/ha or chloroxuron at 5.6 kg/ha could be safely applied after planting but before bud break. Even though initial testing was conducted using clones of northwest poplar (*Populus jackii* 'Northwest'), Walker poplar (*Populus* x *deltoides* 'Walker'), acute willow (*Salix acutifolia*) and laurel willow (*Salix pentandra*) more recent testing has indicated Walker poplar may be adversely affected by linuron application. If these results are confirmed, chloroxuron will be substituted for linuron for Walker poplar production. It should

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[1]Paper presented at the Intermountain Nurseryman's Meeting (Colorado Sate University, Fort Collins, August 13-14, 1985).

[2]Lyle K. Alspach, Herbicide Technician, Investigation Section, Tree Nursery, PFRA, Agriculture Canada, Indian Head, Saskatchewan.

be noted that application of either linuron or chloroxuron should be followed by overhead irrigation to provide soil incorporation.

Many undesirable characteristics of Siberian elm have caused the Tree Nursery to drastically reduce production of this species. In fields used to produce this crop, trifluralin is applied at 1.1 kg/ha and incorporated to a depth of 7 to 10 cm seven days before sowing. Occasionally this trifluralin treatment has been observed to cause some reduction in Siberian elm top growth. This reduction is not of concern as it improves the top to root ratio and the elm are still of sufficient size at harvest time.

The Tree Nursery produces approximately 200,000 choke cherry per year. Linuron is applied at 1.7 kg/ha in late fall after the choke cherry are sown. Precipitation during the fall and winter provide incorporation of the herbicide. This linuron treatment progressed through the Tree Nursery's testing program without complication and after three years, refinement of rate and application timing were established. The treatment has been included in Nursery production practices for a number of years and has not caused any adverse affects on choke cherry sowings.

Bare root conifer production at Indian Head involves a two year period of seedbed growth followed by two years growth in the transplant area: three years for Colorado spruce. Considerable work has been conducted in an attempt to find an acceptable herbicide that can be applied preemergence for weed control in seedbeds of Colorado spruce, white spruce and Scots pine. The most promising herbicide tested, which is unfortunately no longer available, was fluorodifen (Preforan) a Ciba-Geigy product. Other promising herbicides tested included: napropamide (Devrinol), bifenox (Modown) and oxyfluorfen (Goal). The one which is currently of interest and still being tested is oxyfluorfen. Its application has resulted in some injury to conifer seedlings, however a reduction in rates of herbicide application may provide the desired margin of safety. A rate of 0.5 kg/ha is currently being tested.

In the conifer transplant area weed control is provided by linuron application at 2.2 kg/ha after transplanting and at 1.5 kg/ha applied each fall thereafter. Linuron application has not resulted in a residual buildup nor has it been found to have moved beyond a depth of 5.0 cm in the clay loam soil.

All deciduous species which require more than one growing season to produce receive a linuron application at 1.7 kg/ha in the fall of the first year, once the abscission layer has formed. This treatment is particularly effective for control of winter annuals such as flixweed (Descurainia sophia), stinkweed (Thlaspi arvense) and shepherd's-purse (Capsella bursa-pastoris).

Herbicide Treatments Currently Being Tested for Use in Seedling Production

Several herbicides are presently being tested. Alternate treatments for weed control in caragana sowings include: EPTC (Eptam 80% EC), applied and incorporated prior to sowing, and 2,4-DB (Cobutox 40% EC), applied overall when caragana are in the first to fourth trifoliate leaf stage.

Results for the EPTC treatments have been very promising with no significant reduction in the stand or growth of caragana (table 1). At a rate of 4.0 kg/ha, EPTC has consistently provided excellent weed control.

Unfortunately, 2,4-DB has not provided the same kind of consistently promising results that EPTC has (table 2). A greenhouse trial in 1984 and a field study in 1985 resulted in 2,4-DB injury to caragana seedlings even though seedlings in 1982 and 1984 field studies did not show any such injury symptoms. Based on these results further evaluation is needed.

Linuron is currently being tested for use in green ash production. It has been tested in 1982 and 1983 and is scheduled for further testing in 1985. Test results to date indicate the most promising treatment is a fall application of 2.0-2.5 kg/ha applied after sowing (table 2).

Even though tatarian honeysuckle is a minor crop at the Tree Nursery some herbicide work has been conducted on this species Chloramben is the herbicide of interest and has shown considerable promise for preemergence use in honeysuckle sowings. In 1982, chloramben was applied preemergence to plots which had been sown to honeysuckle the previous fall and at 4.0 kg/ha provided fair weed control with no adverse affects on the honeysuckle (table 3). To further pursue this use of chloramben, rates of 4.0 to 6.0 kg/ha were applied in the fall of 1982, after sowing, and in the spring of 1983, before crop and weed emergence. All of the treatments except the 4.0 kg/ha rate, spring applied, provided good to excellent weed control, again without adverse affects on the honeysuckle. An additional study was conducted in 1984, testing rates of 4.0 to 7.0 kg/ha fall applied after sowing or spring applied prior to crop and weed emergence. All of the treatments provided good to excellent weed control with no adverse affects on stand or growth of honeysuckle.

Two factors have been taken into consideration during the planning of the current herbicide studies for poplar and willow cuttings. Firstly, inconsistent weed control with chloroxuron resulting from herbicide adsorption to soil organic matter and secondly, the possible negative effect of linuron application on the rooting and development of Walker poplar cuttings.

In a 1985 field study, the treatments of most interest involved oxyfluorfen at 0.5 and 1.0 kg/ha. Both rates provided satisfactory results for use in production of rooted poplar cuttings. For willow production, it appears rates exceeding

0.5 kg/ha may result in significantly reduced growth.

During grounds maintenance operations, at Indian Head, glyphosate (Roundup 36% SN) was applied to control unwanted brush of which lilac was a component. The lilac was not controlled indicating that the morphology of the lilac leaves and/or physiology of the lilac plants provided some degree of tolerance to glyphosate. In light of this it was decided to conduct a greenhouse screening study using low rates of glyphosate, applied at various leaf-stages. Initial rates tested were 1.0, 1.5 and 2.0 kg/ha applied when the villosa lilac seedlings were in the cotyledon, two and four leaf-stages. Results were very encouraging for all treatments except the 2.0 kg/ha rate, applied at the cotyledon stage, which reduced the stand and resulted in seedling injury.

Since the greenhouse screening in 1982 glyphosate has been tested on three occasions for villosa lilac sowings. The first time, rates of 1.0-2.5 kg/ha applied at the four to eight leaf-stage proved unsatisfactory. In 1983, rates of 0.50 and 0.75 kg/ha showed marginal acceptability: the seedlings recovered and achieved near normal growth in 1984.

In a study conducted in 1985, glyphosate at 0.25, 0.50 and 0.75 kg/ha alone and with the addition of concentrated sulfuric acid at 0.25% volume per volume was applied when villosa lilac were in the six to eight leaf-stage. Results indicate that a rate of 0.50 kg/ha with H_2SO_4 added will provide adequate weed control with some yellowing and stunting of villosa lilac seedlings (table 4). It is expected that these seedlings will recover and achieve normal growth in 1986.

CONCLUSION

As can be seen from the information reported herein, it takes at least three years, even if everything goes well, before a treatment can be considered for inclusion in a nursery's herbicide program. With the development and inclusion of each new herbicide treatment a nursery is able to increase the weed control options available, decrease labor requirements and reduce costs.

Table 1.--Stand, growth and weed control in caragana sowings as affected by EPTC application[1]

Treatment	Rate 1983	Rate 1984	Type of application	Stand 1983	Stand 1984	Growth[2] 1983	Growth[2] 1984	Weed[3] control 1983	Weed[3] control 1984
	(kg/ha)			(#/0.5m)	(#/2m)	(g)			
Check weeded	-	-		57	88	1.16	0.65	-	-
Check not weeded	-	-		100	72	1.89	0.52	0.0**	0.0**
EPTC	2.5	-		71	-	1.27	-	6.0	-
EPTC	3.0	3.0	Pre-sow	96	48	1.27	0.61	7.3	7.0
EPTC	3.5	3.5	incorporated	138	57	1.24	0.50	8.7	6.7
EPTC	4.0	4.0		82	69	1.28	0.48	8.8	8.6
EPTC	-	4.5		-	81	-	0.60	-	7.8

[1]Data based on means of three and four replications in 1983 and 1984, respectively.
[2]Growth: top dry weight per ten seedlings.
[3]Weed control: 0-no control, 9-complete control.
**Significantly less than for best weed control (P=0.01).

Table 2.--Stand, growth, seedling injury and weed control in fall sown green ash during 1983 as affected by linuron application[1]

Treatment	Rate	Time of application	Stand	Growth[2]	Seedling[3] injury	Weed[4] control
	(kg/ha)		(%)	(g)		
Check weeded	-		14	2.2	1.4	-
Check not weeded	-		17	2.2	2.7	0.0++
Linuron	1.5	Fall	16	2.5	3.1	6.1
Linuron	2.0	Fall	14	2.1	22.6	7.5
Linuron	2.5	Fall	16	2.1	19.2	7.8
Linuron	3.0	Fall	19	1.4	19.1	7.0
Linuron	1.5	Spring	19	1.8	13.4	2.3++
Linuron	2.0	Spring	12	1.9	26.8*	8.7
Linuron	2.5	Spring	13	1.7	26.6*	8.4
Linuron	3.0	Spring	14	1.4	53.9**	8.4

[1]Data based on means of four replications.
[2]Growth: top dry weight per seedling.
[3]Seedling injury: percent of seedlings with necrotic leaves.
[4]Weed control: 0-no control, 9-complete control.
*,**Significantly greater than for check weeded (P=0.05) and (P=0.01).
++Significantly less than for best weed control (P=0.01).

Table 3.--Stand, growth and weed control in honeysuckle sowings as affected by preemergence chloramben application[1]

Treatment	Rate 1982	Rate 1983	Rate 1984	Time of application	Stand 1982	Stand 1983	Stand 1984	Growth[2] 1982	Growth[2] 1983	Growth[2] 1984	Weed control[3] 1982	Weed control[3] 1983	Weed control[3] 1984
	(kg/ha)				(#/.3m)	(#/.5m)	(#/.5m)		(g)				
Check weeded	-	-	-		47	83	19	1.7	1.0	10.8	-	-	-
Check not weeded	-	-	-		46	78	21	1.6	1.9	10.2	0.0**	0.0**	0.0**
Chloramben	-	4.0	4.0	Fall after sowing	-	70	19	-	1.6	9.8	-	7.7	6.8
Chloramben	-	5.0	5.0		-	85	24	-	1.4	8.9	-	7.5	7.5
Chloramben	-	6.0	6.0		-	58	26	-	1.6	9.7	-	8.4	7.2
Chloramben	-	-	7.0		-	-	27	-	-	10.1	-	-	7.8
Chloramben	2.0	-	-	Spring prior to crop and weed emergence	45	-	-	1.9	-	-	2.5**	-	-
Chloramben	3.0	-	-		44	-	-	1.7	-	-	4.7*	-	-
Chloramben	4.0	4.0	4.0		53	71	17	1.5	1.6	12.6	6.1	5.0*	6.7
Chloramben	-	5.0	5.0		-	87	23	-	1.5	13.2	-	6.7	7.6
Chloramben	-	6.0	6.0		-	73	21	-	1.6	9.4	-	7.5	8.1
Chloramben	-	-	7.0		-	-	24	-	-	10.9	-	-	7.9

[1]Data based on means of four replications.
[2]Growth: top fresh weight per seedling.
[3]Weed control: 0-no control, 9-complete control.
*,**Significantly less than for best weed control (P=0.05) and (P=0.01).

Table 4.--Preliminary results for seedling injury and weed control in villosa lilac sowings as affected by glyphosate application at the six to eight leaf stage[1]

Treatment	Rate	Seedling[2] injury	Weed[3] control
	(kg/ha)		
Check weeded	-	0.0	-
Check not weeded	-	0.0	0.0
Glyphosate	0.25	0.4	0.4
Glyphosate	0.50	3.3**	2.5
Glyphosate	0.75	3.9**	8.4
Glyphosate plus H_2SO_4	0.25 0.25% v/v	1.4**	0.7
Glyphosate plus H_2SO_4	0.50 0.25% v/v	3.2**	6.9
Glyphosate plus H_2SO_4	0.75 0.25% v/v	4.2**	8.1

[1]Data based on means of four replications.
[2]Seedling injury: 0-no yellowing, 9-severe yellowing.
[3]Weed control: 0-no control, 9-complete control.
**Significantly more than for check weeded (P=0.01).

Forest Tree Nursery Herbicide Studies in the Northern Great Plains: Herbicide Phytotoxicity Tables[1]

Lawrence P. Abrahamson[2]

Abstract.--Eight herbicides (registered for similar uses in the U.S.) were extensively evaluated at 15 forest tree nurseries in Western and Northern United States for weed control on first year seedling nursery beds. Phytotoxicity evaluations of dcpa, napropamide, oxyfluorfen, diphenamid, bifenox, oxadiazon, trifluralin and prometryn on 38 different conifer and hardwood species are presented.

Additional keywords: Enide®, Treflan®, Dacthal®, Caparol®, Devrinol®, Modown®, Goal®, and Ronstar®.

INTRODUCTION

The USDA Forest Service developed a number of nursery herbicide projects in the United States out of a recognition of the potential benefits of herbicidal control of weeds in nursery seedbeds. This paper will concentrate on projects conducted at 15 nurseries in the Great Plains, the Lake States and in New York. The forest tree nurseries were part of the following projects. The cooperative western nursery herbicide project, initiated in 1976, was with cooperation among state, private and federal nurseries, Forest Service Research, State and Private Forestry, National Forest Systems, and State University of New York out of Syracuse. Twenty-eight nurseries in 12 states were involved in this effort which was broken down into three segments, each of three-year duration; the Pacific Coast started in 1976 (Stewart 1977, Owston et al. 1980, Owston and Abrahamson 1984), the Intermountain-Great Basin in 1977 (Ryker and Abrahamson 1980), and the Great Plains in 1978 (Abrahamson 1981, Abrahamson and Burns 1979). In 1979 the Northeastern (NE) Area started an eastern nursery herbicide project in five states cooperating with Purdue University and State University of New York (SUNY) at Syracuse (Holt and Abrahamson 1980). In 1981 the NE Area expanded the eastern nursery herbicide project to the Great Lakes area with eight nurseries (state, federal and private) in three Lake States cooperating with SUNY (Abrahamson and Jares 1984). During 1982 Oklahoma State (Abrahamson 1983) also sponsored a nursery herbicide project of their own in cooperation with SUNY to help the nursery expand on the herbicide studies using different herbicides, tree species and sowing times.

What is important in these projects is that all studies have similar objectives and methodologies and that information developed from one region or study project is supportive of that from other regions. In all these studies the objectives were to identify promising herbicides, develop data for product registration, and demonstrate safe and effective weed control practices for nursery seed beds.

METHODS

The nursery herbicide screening and demonstration projects were initiated as part of a three-year study. During the first year of the three-year study up to ten herbicides (eight of which are represented in Table 1) were screened on two to four major species of spring- and/or fall-sown conifers and/or hardwoods depending on the nursery involved in the study.

Treatments were applied to three-foot long plots in four-foot wide nursery beds with a one-foot untreated buffer between plots. All treatments were installed in a randomized block design with three replications per species. Herbicides were applied with a modified AZ plot pressurized sprayer equipped with check valves and four flat fan 8001 nozzles operated at 20 psi in a water carrier at a volume equivalent to 85 ppa (100 ml/plot). Granular formulations were ocularly applied from a hand shaker uniformly over the plot.

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[1]Paper presented at the Intermountain Nurserymen's Association 1985 Annual Meeting. [University Park Holiday Inn, Fort Collins, August 13-15, 1985].

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Pre-seeding incorporated treatments were applied no more than one day before seeding and incorporated into the top two inches of soil using a garden rake. Post-seeding treatments (Ps) were applied within two days after seeding, except on the fall-sown species which were applied any time after fall seeding but before mulching. Post-germination treatments (Pg) were applied four to six weeks after seedling emergence, except on the fall-sown species which were applied in the spring after mulch was removed and seedlings had emerged.

Herbicidal damage to conifers/hardwoods at the end of the first growing season was evaluated using a ten-point rating scale (0 is complete kill, 10 is no effect) proposed by Anderson (1963). Height of nine randomly selected seedlings and number of seedlings per foot in three randomly selected rows in each plot were also measured to determine chemical effects on germination, seedling growth and survival.

The objectives of the second-year studies were to evaluate the phytotoxicity and weed control effectiveness of three to four herbicides screened from the first-year study to be non-phytotoxic to the species tested and have reasonable weed control of weeds present at that nursery. Phytotoxicity was evaluated by using herbicidal damage ratings (Anderson 1963), seedling survival (number/foot) and height growth (cm). Dosages of 1X, 2X, and 1X + 1X of these herbicides were applied post-seeding and/or post-germination using three-foot long plots in four-foot wide beds with a one-foot untreated buffer between plots. All treatments were installed using a randomized block design with three replications per species. Herbicide treatments were applied by small pressurized sprayer or hand shaker as was done the first year of these studies.

Weed control effectiveness of the best treatments selected from the second year study were evaluated the third year under operational use using nursery application equipment on 100-foot test plots. The herbicides were evaluated for weed control under operational use at the 1X rate of application applied post-seeding alone, or post-seeding and post-germination. Phytotoxicity rating, survival and height measurements were also recorded from these operational plots.

RESULTS AND DISCUSSION

Since each nursery is a study in itself, this paper will only concentrate on studies completed at 15 nurseries in the Great Plains, the Lake States and New York (Abrahamson 1984). Phytotoxicity data from these nurseries is presented in Tables 2-15, listed by herbicides tested under each species. The tables are summaries of all the phytotoxicity studies and indicate; 1) those fall- and/or spring-sown seedlings where the herbicide has been safely applied at rates indicated without stunting or germination reduction (x); 2) herbicides that appear to be promising at rates indicated, but because of possible phytotoxic problems implied in some of our studies, these should be thoroughly tested before using at your nursery (o); 3) herbicides that should not be used at rates indicated because of severe phytotoxic damage (-). One herbicide that should be elaborated on is napropamide. Napropamide is used at the lower rate (1.5 lbs ai per acre) when the nursery soil has below 1 percent organic matter, otherwise the higher rate (3.0 lbs ai per acre) is normally used. Napropamide is safe to use post-seeding on most spring-sown conifer species tested, but caused severe stunting when applied post-seeding to fall-sown conifer species in the Lake States study. Napropamide applied post-germination to both spring- and fall-sown conifers caused no phytotoxic problems.

Weed control expressed in terms of hand-weeding time, or "how much time can herbicides save you versus hand-weeding" is one of the most important aspects of these studies. In the Great Plains study (Abrahamson 1981) on spring-sown species the post-seeding applications were as effective as the post-seeding plus post-germination applications for total season weed control. The Norman Nursery in Oklahoma is an example (Abrahamson 1983) of the type of savings in time and money that can be expected from these herbicides when used in forest tree nurseries.

Hand weeding time at the Norman Nursery was reduced by an average of 80 percent for all herbicides applied only in the spring (Ps) while those applied in both the spring and a second application five to six weeks later (Ps + Pg) reduced hand weeding time by an average of 87 percent. Based on minimum wage of $3.35 per hour, this would amount to an average gross saving of $4,600 per acre of seedbed (without figuring in cost of herbicide or application costs) weeded six times with a mean weeding time of 283 man hours per acre untreated seedbeds at Norman (Abrahamson 1983).

SUMMARY

There have been numerous trials, studies and tests of various herbicides at many different nurseries that have demonstrated the safe and effective use of dcpa, napropamide, oxyfluorfen, diphenamid, bifenox, oxadiazon, trifluralin, and prometryn on various conifer and/or hardwood first year seedling nursery beds. These herbicides have reduced the time required to hand-weed nursery beds by 80-87 percent when applied at sowing time alone or with a second application four to six weeks later. Over $4,000-$7,000 per acre of seedbed could be saved by using these herbicides over hand-weeding alone.

However, the safety and effectiveness of any herbicide should be tested at each nursery before operational use. These herbicide trials are urged because there is a strong possibility of differential results from varied interactions of

Table 1. Herbicides, rates, and application timings used in the Nursery Herbicide Studies Conducted by SUNY.

Herbicide	Formulation	Manufacturer	(lb ai/A)	Application Timing[1]		
				Pre-Seeding Incorporation or Post-Seeding	Post-Germination	Post-Seeding Plus Post-Germination
Diphenamid	Enide 50W; 90W	Upjohn	4.0	x	x	x
Trifluralin	Treflan 4EC	Elanco	0.75	x	-	-
DCPA	Dacthal W-75	Diamond-Shamrock	10.5	x	x	x
Prometryn	Caparol 80W	Ciba-Geigy	1.0	x	x	x
Napropamide	Devrinol 50W	Stauffer	1.5/3.0	x	x	x
Bifenox	Modown 80W; 4F	Rhone-Poulenc	3.0	x	x	x
Oxyfluorfen	Goal 2E; 1.6E	Rohm & Haas	0.5	x	x	x
Oxadiazon	Ronstar G	Rhone-Poulenc	1.0	x	x	x
Napropamide & Bifenox	Tank mix		1.0+3.0	x	x	x

[1] Pre-seeding incorporation: incorporated into top 2 inches of soil immediately before seeding.
Post-seeding: broadcast applied to soil immediately after seeding.
Post-germination: broadcast applied to soil 4 to 5 weeks after seedling emergence.
Post-seeding plus post-germination: two separate applications at the full recommended rate.

different mixtures of tree and weed species, soil and climatic factors, and cultural practices at different nurseries. If a particular herbicide has never been used at your nursery, several years of trials are advisable because of variations in effects caused by different weather conditions. Trials should include "double doses" to evaluate the safety limits on crop seedlings and leave an untreated control to properly evaluate the effects of the herbicide.

LITERATURE CITED

Abrahamson, L.P. 1981. Herbicide trials for weed control in Great Plains Forest tree nurseries. In: Proceedings of the 33rd Annual Meeting of the Forestry Committee, Great Plains Agr. Council, June 1981, Lubbock, TX, Great Plains Agr. Council Publ. #102; p. 65-102.

Abrahamson, L.P. 1983. Herbicides, an important component of the weed control program at Oklahoma State (Norman) Nursery. In: Proceedings of the 1982 Southern Nurserymen's Conf., Southern Region, U.S. Forest Service, Technical Publ. R8-TP4, p. 171-191.

Abrahamson, L.P. 1984. Forest tree nursery herbicide studies in the Northeastern United States: Highlights of research results. In: Proceedings of the Workshop: Weed Control in Tree Nurseries, July 17-18, 1984, PFRA Tree Nursery, Indian Head, Saskatchewan. Agriculture Canada, PFRA. p. 6-21.

Abrahamson, L.P. and K.F. Burns. 1979. Herbicide screening for weed control in western forest tree nurseries - Great Plains Segment. AFRI, Syracuse, NY, Res. Report No. 41; 15 pp.

Abrahamson, L.P. and T. Jares. 1984. Forest tree nursery herbicide studies in the Lake States and New York: Highlights of research results. In: Northeast Area Nursery Supervisors Conference Proceedings, August 6-9, 1984, Dover, Delaware, Sponsored by Delaware Forest Service. 25 pp.

Anderson, W.H. 1963. A system for evaluating effective weed control in forest nurseries. Tree Planter's Notes (Oct.):19-23.

Holt, H.A. and L.P. Abrahamson. 1980. Developing weed control programs for forest nurseries in central U.S. In: Abstracts - 1980 Meeting of Weed Sci. Soc. of Amer., Feb. 5-7, 1980, Toronto, Canada, p. 51.

Owston, P.W., R.E. Stewart, N.W. Callan, and L.P. Abrahamson. 1980. Evaluation of herbicides for weed control in Pacific Coast forest tree nurseries. In: Abstracts - 1980 Meeting of Weed Sci. Soc. of Amer., Feb. 5-7, 1980, Toronto, Canada, p. 51-52.

Owston, P.W. and L.P. Abrahamson. 1984. Weed management in forest nurseries. In: Duryea, M.L. and T.D. Landis (eds.), Forest Nursery Manual: Production of Bareroot Seedlings. Martinus Nijhoff/Dr. W. Junk Publishers. The Hague/Boston/Lancaster for Forest Research Laboratory, Oregon State Univ., Corvallis. 386 p. (p. 193-202).

Ryker, R.A. and L.P. Abrahamson. 1980. Western forest nursery herbicides study, Rocky Mountain-Great Basin Segment. In: Abstracts - 1980 Meeting of Weed Sci. Soc. of Amer., Feb. 5-7, 1980. Toronto, Canada, p. 52.

Stewart, R.E. 1977. Herbicides for weed control in western forest tree nurseries. Proceedings, Western Society of Weed Science, 30:78-79.

TABLE 2: Phytotoxic effects of herbicides tested on first year ponderosa and lodgepole pine nursery beds.

Ponderosa Pine

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		x	x	x
oxadiazon	*		x	x	x
trifluralin	*		x		
napropamide & bifenox	*		x	x	x

Lodgepole Pine

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		x	x	x
trifluralin	*		o		
napropamide & bifenox	*		o	x	o

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 3: Phytotoxic effects of herbicides tested on first year loblolly and Austrian pine nursery beds.

Loblolly Pine

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		o	x	o
trifluralin	*		x		
napropamide & bifenox	*		o	x	o

Austrian Pine

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		o	x	o
diphenamid	*		x	x	x
bifenox	*		o	x	o
trifluralin	*		x		
napropamide & bifenox	*		o	x	o

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 4: Phytotoxic effects of herbicides tested on first year white and Scotch pine nursery beds.

White Pine

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*	*	x	x	x
napropamide	*		x	x	x
napropamide		*	-	x	-
oxyfluorfen	*	*	x	x	x
diphenamid	*	*	x	x	x
bifenox	*	*	x	x	x
oxadiazon	*	*	x	x	x
trifluralin	*		x		
prometryn	*	*	x	x	x
napropamide & bifenox		*	o	x	o

Scotch Pine

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		x	x	x
oxadiazon	*		x	x	x
trifluralin	*		x		
prometryn	*		x	x	x

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 5: Phytotoxic effects of herbicides tested on first year red and jack pine, and Colorado blue spruce nursery beds.

Red and Jack Pine

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*	*	x	x	x
napropamide	*		x	x	x
napropamide		*	-	x	-
oxyfluorfen	*	*	x	x	x
diphenamid	*	*	x	x	x
bifenox	*	*	x	x	x
oxadiazon	*	*	x	x	x
prometryn	*	*	x	x	x
napropamide & bifenox	*		x	x	x
napropamide & bifenox		*	-	x	-

Colorado Blue Spruce

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		o	x	o
dcpa		*	x	x	x
napropamide	*		x	x	x
napropamide		*	o	x	o
oxyfluorfen	*	*	x	x	x
diphenamid	*		x	x	x
bifenox	*		o	x	o
bifenox		*	x	x	x
oxadiazon	*	*	x	x	x
trifluralin	*		x		
prometryn	*	*	x	x	x
napropamide & bifenox	*	*	o	x	o

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 6: Phytotoxic effects of herbicides tested on first year white and Norway spruce nursery beds.

White Spruce

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*	*	x	x	x
napropamide	*		x	x	x
napropamide		*	o	x	o
oxyfluorfen	*	*	x	x	x
diphenamid	*	*	x	x	x
bifenox	*	*	x	x	x
oxadiazon	*		x	x	x
oxadiazon		*	o	x	o
trifluralin	*		x		
prometryn	*	*	x	x	x
napropamide & bifenox		*	x	x	x

Norway Spruce

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		x	x	x
oxadiazon	*		x	x	x
trifluralin	*		x		
prometryn	*		x	x	x

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 7: Phytotoxic effects of herbicides tested on first year Japanese larch, eastern red cedar, and white cedar nursery beds.

Japanese Larch

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	o	x	o
oxyfluorfen		*	x	x	x
diphenamid		*	x	x	x
bifenox		*	x	x	x
oxadiazon		*	x	x	x
trifluralin		*	x		
prometryn		*	x	x	x

Eastern Red Cedar

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	x	x	x
oxyfluorfen		*	x	x	x
diphenamid		*	x	x	x
bifenox		*	o	x	o
oxadiazon		*	x	x	x
trifluralin		*	x		
napropamide & bifenox		*	o	x	o

White Cedar

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	o	x	o
oxyfluorfen		*	-	x	-
diphenamid		*	x	x	x
bifenox		*	-	x	-
oxadiazon		*	x	x	x
trifluralin		*	x		

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 8: Phytotoxic effects of herbicides tested on first year caragana, Russian olive, and black locust nursery beds.

Caragana

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		-	x	-
oxyfluorfen	*		-	x	-
diphenamid	*		x	x	x
bifenox	*		-	x	-
trifluralin	*		o		
napropamide & bifenox	*		-	x	-

Russian Olive

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		-	x	-
trifluralin	*		x		
napropamide & bifenox	*		-	x	-

Black Locust

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*			x	
napropamide	*		x	x	x
oxadiazon	*			x	
trifluralin	*		-		

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 9: Phytotoxic effects of herbicides tested on first year hard and silver maple, and black walnut nursery beds.

Hard Maple

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	-	x	-
oxyfluorfen		*	o	-	-
diphenamid		*	x	x	x
bifenox		*	-	x	-
oxadiazon		*	-	x	-
trifluralin		*	o		
prometryn		*	x	-	-
napropamide & bifenox		*	-	x	-

Silver Maple

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		-	x	-
napropamide	*		o	x	o
oxyfluorfen	*		-		-
diphenamid	*		-	o	-
bifenox	*		-		-
oxadiazon	*			x	
napropamide & bifenox	*		-		-

Black Walnut

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	o	x	o
oxyfluorfen		*	x	o	o
diphenamid		*	x	x	x
bifenox		*	x	x	x
oxadiazon		*	x	x	x
trifluralin		*	x		

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 10: Phytotoxic effects of herbicides tested on first year cotoneaster, Siberian elm, and honeysuckle nursery beds.

Cotoneaster

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	o	x	o
oxyfluorfen		*	o	-	-
diphenamid		*	x	x	x
bifenox		*	x	o	o
oxadiazon		*		x	
napropamide & bifenox		*	o	o	o

Lacebark Elm

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		o	x	
napropamide	*		-	x	-
oxyfluorfen	*		-		-
diphenamid	*		-	o	-
bifenox	*		-	-	-
oxadiazon	*			x	
trifluralin	*		o		
napropamide & bifenox	*		-		

Honeysuckle

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	-	-
napropamide		*	x	x	x
oxyfluorfen		*	o	-	-
diphenamid		*	o	o	o
bifenox		*	x	o	o
oxadiazon		*		-	-
trifluralin		*	x		
napropamide & bifenox		*	x	o	o

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 11: Phytotoxic effects of herbicides tested on first year white and green ash, and silky dogwood nursery beds.

White Ash

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	x	x	x
oxyfluorfen		*	x	-	-
bifenox		*	o	x	o
oxadiazon		*	-	x	-
trifluralin		*	x		
prometryn		*	x	-	-

Green Ash

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		-	x	-
trifluralin	*		x		
napropamide & bifenox	*		-	x	-

Silky Dogwood

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	-	-
napropamide		*	-	x	-
oxyfluorfen		*	-	-	-
diphenamid		*	x	x	x
bifenox		*	-	-	-
oxadiazon		*	-	-	-
trifluralin		*	x		

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 12: Phytotoxic effects of herbicides tested on first year euonymus, hackberry, sycamore, and choke cherry nursery beds.

Euonymus

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*		x	
napropamide		*		x	
diphenamid		*		o	
oxadiazon		*		x	

Hackberry

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*		-	-
napropamide		*		x	
diphenamid		*	o	x	o
oxadiazon		*		x	

Sycamore

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		-	o	-
napropamide	*		o	o	o
oxyfluorfen	*		-		-
diphenamid	*		o	x	o
bifenox	*		-		-
oxadiazon	*			o	
napropamide & bifenox	*		-		-

Choke Cherry

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*		-	-
oxyfluorfen		*		-	-

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 13: Phytotoxic effects of herbicides tested on first year yellow birch, American plum, honeylocust, and lilac nursery beds.

Yellow Birch

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	-	-	-
napropamide		*	-	x	-
oxyfluorfen		*	-	-	-
diphenamid		*	x	x	x
bifenox		*	-	-	-
oxadiazon		*	-	-	-
trifluralin		*	-		
prometryn		*	x	-	-

American Plum

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*		o	
oxyfluorfen		*		o	

Honeylocust

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*			x	
oxyfluorfen	*			o	

Lilac

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*			x	
oxyfluorfen	*			-	-

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 14: Phytotoxic effects of herbicides tested on first year redbud and catalpa nursery beds.

Redbud

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*			x	
napropamide	*		-	x	-
diphenamid	*			o	
oxadiazon	*			x	
trifluralin	*		o		

Catalpa

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*			x	
napropamide	*		x	x	x
diphenamid	*			x	
oxadiazon	*			x	
trifluralin	*		-		

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use
- = severe phytotoxic effects, Do Not Use.

TABLE 15: Phytotoxic effects of herbicides tested on first year poplar and willow cutting nursery beds.

Poplar Cuttings

Herbicide	Spring Plant	Fall Plant	Post-Plant	Post-Sprouting	Post-Plant & Sprouting
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	o	o
diphenamid	*		x	x	x
bifenox	*		x	o	o

Willow Cuttings

Herbicide	Spring Plant	Fall Plant	Post-Plant	Post-Sprouting	Post-Plant & Sprouting
dcpa	*		x	x	x
napropamide	*		o	x	o
oxyfluorfen	*		x	o	o
diphenamid	*		x	x	x
bifenox	*		x	o	o

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

Herbicides for Conifers: What's New[1]

Robyn L. Darbyshire[2]

Abstract.--Of recent interest to conifer nurserymen are the preemergence grass herbicides, with Poast (sethoxydim) and Fusilade (fluazifop-butyl) currently registered for use on conifers. Information about these herbicides and herbicides for yellow nutsedge control is discussed. Split applications, applications with low carrier volumes, and a new publication on backpack sprayers are also mentioned.

CHEMICALS

Postemergence Grass Herbicides

Introduction

The so-called "new grass killers" are currently receiving a lot of interest. They are not so new anymore, and are more commonly referred to as postemergence grass killers. Poast (sethoxydim) and Fusilade (fluazifop-butyl) are currently registered for use on non-bearing crops, including conifers. Another herbicide in this group is Verdict (haloxyfop-methyl--also known as Dowco 453). Verdict is not yet registered for use on conifers, but probably will be registered for this use in the future. Other graminicides you may have heard of include Assure, Hoelon, and Whip. These herbicides are active at fairly low rates (less than 0.5 pound active ingredient per acre), and kill both aboveground and belowground parts of the plant after being translocated to root and shoot meristems. They exhibit varying degrees of soil activity, with Fusilade having one of the shortest periods of soil activity (less than one month) and Verdict having one of the longest (up to one year). Newer versions of these graminicides will probably have even greater soil activity and persistence. Most of the information that follows on these herbicides will concern Poast and Fusilade.

Selectivity

Even though these herbicides are grouped together, they each exhibit a different chemistry and selectivity. To decide which of these herbicides to apply, you need to know the grass species that you are trying to control. Recent work in western Oregon has shown that certain herbicides are more effective against certain grass species (Brewster, 1984). For example, Verdict was more active against annual bluegrass than Poast or Fusilade, and Poast and Verdict control Italian ryegrass better than Fusilade. Fusilade however, is best for control of quackgrass. In general, Verdict is the most active herbicide of the three on young (4-5 leaf or 1-2 tiller stages) grasses. Some other work has shown however, that Poast may be more active on older grasses than Fusilade (Whitson, et al, 1985). None of these herbicides are effective against broadleaf weeds, rattail fescue or the fine fescues, and control of perennial grasses may take more than one application to get the desired result.

Additives

In applying these chemicals, READ THE LABEL CAREFULLY. The recommendations for crop oils and surfactants vary, depending on the chemical and the crop species. These additives are needed to increase plant uptake of the herbicides, especially under adverse conditions. Some of the crop phytotoxicity attributed to these herbicides, particularly when applied under warm and humid conditions, is thought to be due to the crop oils. If you suspect a problem, try treating a small area without the use of crop oil, another small area with the additive alone, and a third area with the herbicide plus the additive. The grass control will not be as good, but you may be able to determine if the additive is causing the phytotoxic effect. For further information on testing herbicides in nurseries, consult Sandquist, Owston, and McDonald (1981).

Mode of Action

These herbicides are translocated to the grass meristems within one to two hours of application, but obvious visual symptoms do not appear for at least two weeks. A few days after application however, the newest leaf should detach easily, and a longitudinal section of the stem should show discolored meristematic tissue at the newest node. As with most herbicide applications, these herbicides are most effective on smaller grasses. It is also important that the grasses be actively growing and unstressed by moisture, mowing, or other herbicide treatments, as these chemicals are translocated within the plant and require an intact plant to be most effective.

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[1] Paper presented at the 1985 Intermountain Nurseryman's Association Meeting. [Fort Collins, Colorado, August 13-15, 1985].

[2] Research Assistant, Nursery Technology Cooperative, Department of Forest Science, Oregon State University, Corvallis, Oregon.

Crop Phytotoxicity

Reported problems with these chemicals include possible phytotoxicity due to the crop oil. Use of these graminicides prior to the application of a broadleaf herbicide in some horticultural crops has resulted in damage to the crop due to greater uptake of the broadleaf herbicide by the crop. Tank mixes with broadleaf herbicides in horticultural crops have shown reduced activity, possibly due to reduced herbicide uptake (William, 1984).

Yellow Nutsedge Control

Yellow nutsedge is a weed of increasing importance. Recent work by Pereira (1985) has concentrated on the control of tuberization rather than control of top growth. If glyphosate is used to control this weed, it should be applied earlier than previously thought for greater control of tuberization. Another herbicide for nutsedge control is Dual (metolachlor). Two or more years of Dual applications were found to give good control in fruit orchards. If a serious infestation is present, you may need to rotate into a crop for which Dual is registered (corn, beans, some ornamentals) to eliminate the nutsedge.

Oregon State University Nursery Technology Cooperative (NTC)

The Nursery Technology Cooperative (NTC) began screening experimental herbicides for bareroot nurseries in May 1984. The screening program has five phases, each with its own objective:

I. International Plant Protection Center (IPPC) Multicrop Screening Program
   Objective: To provide phytotoxicity information on experimental chemicals and to aid the selection of promising chemicals for further screening.
II. Greenhouse Screening
   Objective: To obtain more information on phytotoxicity and timing of application for chemical weed control methods.
III. First-Level Nursery Screening
   Objective: To evaluate new weed control treatments, primarily for crop damage and secondarily for weed control.
IV. Second-Level Nursery Screening
   Objective: To further investigate crop damage, weed control, economics, and specific concerns such as residual effects in the soil.
V. Operational Trials
   Objective: To refine the weed control method and obtain more economic data before operational use.

The current NTC screening program involves phases I and II. Our major crop emphasis so far has been Douglas-fir and ponderosa pine. We will begin screening on other conifers in October 1985. The first phase III experiments are planned for Spring 1986.

As promising, non-phytotoxic chemicals are identified in phases I-III, the NTC will proceed with phases IV and V, culminating (we hope) in new product registrations.

APPLICATION TECHNIQUES

Application Monitors

Improperly calibrated application equipment can lead to costly mistakes. Applications with backpack sprayers and granule spreaders are especially prone to overapplication. Recalibrate the applicator at least once a year. For additional insurance, computerized application monitors are also available ($1500-$2000) and are especially useful for getting better results from applications using low carrier volumes or with herbicides that are applied at very low rates.

Low Carrier Volumes

Low carrier volumes have been found to enhance the herbicidal activity of Poast, Fusilade, and Roundup (glyphosate) (William, 1985; Buhler and Burnside, 1984). Most of these herbicides are applied in 20 or more gallons of water per acre, usually to improve coverage. Weed control with all three herbicides however was found to be better with 10 to 15 gallons of water per acre, perhaps because the individual droplets were more concentrated. When using such low carrier volumes, 80015 or micromax nozzles and emitters are needed.

Backpack Sprayer Comparisons

Nurseries that use backpack sprayers may be interested in a new publication that compares various types of backpack sprayers (Fisher and Deutsch, 1984). This report analyzes 37 different kinds of sprayers. Recommendations of one sprayer over another are not given, but desirable and undesirable features of different sprayers are illustrated.

Split Application

The earlier-mentioned work by Pereira (1985) on nutsedge control and a recent paper by South (1985) have found split applications of herbicides to be more effective than applying the whole recommended dose at once. South notes that the lower dosage, more frequent applications don't let the weeds get too large, and that the smaller weeds are easier to control. More frequent applications of Goal (oxyfluorfen) allow a chemical barrier to be maintained on the soil surface. A drawback to this technique, especially with Goal, is that timing is critical in avoiding crop phytotoxicity. Getting good coverage can also be a problem.

Conclusion

It is always good to keep up with the latest information, but it is also important to prevent and anticipate any weed problems before they

occur. Remember also that repeated use of a single herbicide may create more problems than it solves due to the development of resistant weeds or a shift in the weed population to weed species that are tolerant of the herbicide. It is important to use a combination of techniques to have the most efficient and economical weed control.

LITERATURE CITED

Brewster, B.D. 1985. Efficacy of grass herbicides. Pacific Northwest Weed Topics. 84(4):1.

Buhler, D.D. and O.C Burnside. 1984. Effect of application factors on postemergence phytotoxicity of fluazifop-butyl, haloxyfop-methyl and sethoxydim. Weed Science 32:574-583.

Fisher, H.H. and A.E. Deutsch. 1984. Lever operated knapsack sprayers. A practical scrutiny and assessment of features, components and operation. Implications for purchasers, users and manufacturers. International Plant Protection Center, Oregon State University, Corvallis, Oregon. IPPC Document #53-A-84. 32 pages.

Pereira, W. 1985. Yellow nutsedge (Cyperus esculentus control with herbicides: the role of tuberization. Ph.D. Thesis (unpublished). Oregon State University. 161 pages.

Sandquist, R.E., P.W. Owston, and S.E. McDonald. 1981. How to test herbicides at forest tree nurseries. USDA Forest Service. Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-127. 24 pages.

South, D.B. and D. Stringfield. 1985. An old application technique proves useful when used with a modern herbicide. Auburn University Southern Forest Nursery Management Cooperature. Report 19. 5 pages.

Whitson, T.D., R.D. William, R. Parker, D.G. Swan, and S. Dewey, compilers. 1985. Pacific Northwest Weed Control Handbook. Extension Services of Oregon State University, Washing State University, and the University of Idaho. 213 pages.

William, R.D. 1985. Low water volumes improve Roundup activity. Pacific Northwest Weed Topics. 85(2):8.

Principles, Procedures, and Availability of Seedling Quality Tests[1]

Kenneth R. Munson[2]

Abstract.--As seedling quality tests move from the research to the operational realm, users and potential users must become knowledgeable about the basis for various tests. Without a basic understanding, vigor testing will remain a black-box. This paper condenses and reviews the principles and procedures behind measurements now considered operational: Morphology, mineral nutrition, water status, frost-hardiness, survival, dormancy release, and root growth potential. Tests are now available from three private companies and one university. Seedlings sent for testing should be representative of the lot, and transported in such a way that vigor is not reduced. Cooperative studies to correlate test results and seedling performance in the field are encouraged. The potential benefit of seedling quality testing can be very high relative to the cost.

INTRODUCTION

Seedling quality is a topic that has been discussed by nursery managers and reforestation foresters for several decades. Morphological traits were the focus of early seedling growers and users, while recently the emphasis has been on physiological quality, or vigor. Many methods used to characterize seedling quality that heretofore were experimental are now being used as operational tests. Different tests and different reasons for testing are being employed. At this point in time the usefulness of these tests as a measure of seedling vigor is based on both intuitive reasoning and empirical evidence.

Operational vigor tests, for such seedling features as frost-hardiness and root growth potential, have been available for only a few years. There is most likely some confusion about the principles and procedures of the various tests. Many potential users probably view vigor testing as a "black box", and are hence rather skeptical to the notion of using vigor tests as a means of quantifying seedling quality.

The purpose of this paper is to help clarify the issue by briefly reviewing the rationale for seedling quality testing, the tests that are now available on an operational basis, and the principles and procedures upon which the tests are based. Finally, a listing of organizations which offer a seedling testing service, and sampling and shipping recommendations are provided.

1/ Paper presented at the Intermountain Nurseryman's Assoc. meeting, Ft. Collins, CO, August 13-15, 1985.

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RATIONALE FOR SEEDLING QUALITY TESTING

There are several reasons for testing seedling quality (Faulconer and Thompson 1985; Duryea 1985). From the perspective of a nursery manager, test results can be used to:

- o Demonstrate stock quality to a customer.
- o Guide the implementation of certain practices.
- o Assess the affects of certain practices.
- o Cull seedling lots that have a low expected field performance.

On the other hand, a seedling user (regeneration forester) might use test results to:

- o Match seedlings with certain characteristics to specific sites.
- o Identify if, and at what step, seedling quality falldown occurs during the handling and planting phase.
- o Cull seedlings of low vigor before the cost of planting has been incurred.
- o Determine if special handling practices are necessary.
- o Determine if plantation success or failure was due to stock quality or other factors.

OPERATIONAL TESTS

Many procedures for characterizing seedling quality have been tested (Ritchie 1984), some with more success than others. In his review, Ritchie proposed a logical separation of seedling attributes for which measurements can be made : material attributes and performance attributes. Following is a modified list of these attributes for which tests are considered operational:

Material Attributes	Performance Attributes
o Morphology	o Frost-Hardiness
o Height, stem diameter	o Survival - Unstressed
	o Survival - Stressed

A few of these measurements require only limited equipment and can be made at the nursery or in the field. Most of the measurements, however, require trained personnel, rather expensive equipment and/or a facility for maintaining constant environmental conditions.

It is important that a user of test information have an understanding or at least an appreciation for the biological basis of each test. Only under this condition can useful interpretations of the data be made.

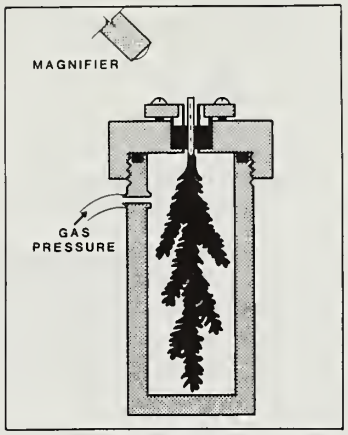
PRINCIPLES AND PROCEDURES

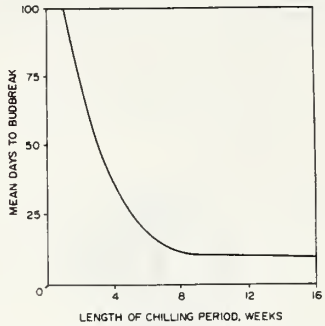
As noted earlier, one purpose of this paper is to capsulize the principles and procedures of the tests that are now considered to be operational. Information about each test will be presented in table form; the reader is referred to specific references for more detail about specific tests.

The following extended table lists the principle(s) upon which a test is based, and a simplified procedure for taking a measurement. This is not intended to serve as a user's guide to vigor testing, but rather an overview from which more detailed inquiries can be made.

Table 1.--Principles upon which seedling quality testing is based, along with simplified measurement procedures.

Attribute	Principle	Procedure	Reference
Morphology			
o Height	o Correlated to needle number, thus a measure of photosynthetic capacity and transpirational area. o Positive relationship between height growth and initial height.	o Meter stick, electronic device o Standard position; e.g., cotyledonary scar to base of bud.	Thompson, 1985
o Diameter	o Better correlated than height to survival. o Good correlation with dry weight. o Larger diameter, more structural support and protection.	o Vernier caliper or simple guage. o Measure at a standardized position. o Stem cross-section is not a uniform diameter.	Thompson, 1985
o Dry Weight	o Correlated to survival and growth as are height and diameter. o Good relationship with photosynthetic area. o Destructive technique. o Easier to use height and/or diameter.	o Rinse tissue, oven dry. o 65° C, 24 hours. o Weigh samples on a balance. o Weigh shoot and root separately to determine ratio.	Thompson, 1985
o Shoot/Root	o Measure of balance between the transpirational area (shoot) and the water absorbing area (root). o Contradictory as an index of field performance.	o Dry weight or volume displacement method. o Shoot weight divided by root weight.	Burdett, 1979
o Bud Height	o Correlated with number of needle primordia and field growth. o Related to vigor at time of dormancy induction.	o Sever bud at base. o Measure with vernier calipers.	Thompson, 1985
Mineral Nutrition	o Certain mineral elements are essential components of plant structure or biochemical functions. o Deficiency of an element will reduce vigor and growth.	o Take good, clean, representative samples. o Stem and foliage for 1-0's, foliage only for older stock. o Oven dry, 65° C, 24 hours. o Grind, dry ash, analyze.	Landis, 1985

Attribute	Principle	Procedure	Reference
Water Status	o Water required to maintain tugor, transport nutrients, facilitate biochemical processes. o If water potential = 0, a plant's water requirements are fully satisfied. o As water content decreases, w.p. becomes more negative (now expressed as megapascals, 1 MPa = 10 bars). o Primary use in irrigation scheduling, dormancy induction and in lifting operation.	o Pressure chamber method.  o Place leaf or stem in chamber. o Increase pressure in chamber with compressed N_2 gas until sap appears at cut surface. o Record pressure on guage.	Joly, 1985
Frost-hardiness	o The susceptibility of seedlings to freezing damage changes naturally with the seasons and artificially with cultural practices. o Hardier seedlings are more resistant to lifting, handling and planting stresses. o Freeze damage is usually dehydration. o Rate of temperature drop and time at minimum temperature are important variables in the test.	o Sample whole seedlings. o Place seedlings in a freezer with a lower minimum temperature of at least -25° C. o Begin at 0° C, drop at 5° C/hr, hold at minimum temperature for 2 hours, raise at 10° C/hr. o Run at 3 temperatures (use fresh samples each time) that bracket LT_{50} (temperature at which 50% die). o Hold seedlings in greenhouse for 1 week, allowing time for damage symptoms to appear. o Evaluate and assign a damage index rating to buds, needles and stem. o Plot numbers on graph paper and interpolate LT_{50}. o Seedlings can also be evaluated with an electrical conductivity meter after freezing. o Uniform test conditions are important.	Glerum, 1985
Dormancy Release	o Dormancy develops in response to environmental signals, but can be influenced by cultural practices. o For seedlings to have maximum vigor, their annual cycle must be in phase with the natural environment. o Relationship between chilling period and days to bud break (refer to graph on next page).	o Whole seedlings are potted and placed in a greenhouse, 20-25° C, 16 hr. daylength. o Held for a set period of time (usually 28 days) and evaluated for terminal and lateral bud burst. o Often done in conjunction with the 28-day root growth potential test. o Data presented as % terminal bud break.	Lavender, 1985

Attribute	Principle	Procedure	Reference
Dormancy Release (Con't)	 o Once chilling requirements have been met, buds become active in response to rising temperatures.		
Survival (Unstressed)	o Observe seedlings under ideal growth conditions. o Should reveal the capacity or potential of a lot to survive.	o Pot 20-30 whole seedlings (or some representative sample), place in a greenhouse. o 20-25° C, 16 hr daylength, 28 days to 2 months. o Tally living and dead seedlings, express as % survival.	McCreary and Duryea, 1985
Survival (Stressed)	o Assumes the normal stresses encountered during planting and first-year establishment can be roughly simulated by exposing seedlings to artificial stress. o Roots are probably the most susceptible to damage.	o Sample 30 seedlings, wash roots, pat dry. o Suspend seedlings in a hot, dry chamber or room. o 32° C, 30% humidity, 15 min. o Remove seedlings, place in water for 5 min. o Evaluate for mortality after 2 weeks, 1 month, and 2 months. o Usually done in conjunction with 30 unstressed seedlings.	McCreary and Duryea, 1985
Root Growth Potential	o Outplanting survival is often a function of how quickly a seedling re-establishes the intimate contact of its roots with the soil. o This is accomplished by initiating and elongating roots. o RGP is a measure of a seedling's capacity to do so under ideal growing conditions. o RGP accumulates in the nursery and is expressed the following year in early spring. o RGP can be influenced by nursery environment, and cultural and and handling practices. o Good correlations between RGP (at planting) and survival and growth. o Hypothesized that the relationship between RGP and field performance is due to a close linkage between RGP, cold-hardiness, and stress resistance, rather than growth of new roots *per se*.	o Select 20-30 seedlings that represent the lot to be tested. o Wash the roots and pot with a 1:1 mix of peat or perlite : vermiculite. o Water the pots initially, and keep near field capacity. o Place in a greenhouse and maintain as uniform environmental conditions as possible. o 20° or 25° C day/night temperature and 16 hr daylength is satisfactory. o RGP is sensitive to temperature, moisture and light. o After 28 days, quantify new root growth. o Total counts or length measurements may be used, but for practical purposes, tallying root codes is satisfactory.	Ritchie, 1985

Attribute	Principle	Procedure	Reference
Root Growth Potential (Con't)	o RGP is presently the most widely used performance attribute of seedling quality.	Example: Code — Description 0 — No new roots 1 — Some <1 cm 2 — 1- 10>1 cm 3 — 11- 30>1 cm 4 — 31- 60>1 cm 5 — 61-100>1 cm 6 — 100+ >1 cm o Data can be averaged or expressed as a frequency distribution. Alternate Methods o 7-day growth room test. o 7 or 28 day hydroponic test. o Shorter tests are done at higher temperatures; e.g., 25-30° C.	

ORGANIZATIONS OFFERING SEEDLING TESTING SERVICES

Table 2 lists the organizations which now offer a range of seedling testing services in the northwest. Most organizations are flexible enough to accommodate special services or handling practices when given advance notice.

Seedling water status is usually measured at the nursery or outplant site. The procedure requires a "pressure chamber," which can be purchased from PMS, Inc. in Corvallis, Oregon (503/752-7926, cost is roughly $1,500).

Table 2.--Organizations offering a range of seedling testing services in the Northwest.

Source	TESTS AVAILABLE								
	RGP 28-day	RGP 7-day	Frost-Hardiness	Morph-ology	Dormancy Release	Survival Un-Stressed	Survival Stressed	Frost Damage Assessment	Special Services
1. International Paper Co. 34937 Tennessee Rd. Lebanon, OR 97355 Contact: Ken Munson 503/243-3273 Jay Faulconer 503/259-2651	X		X	X	X	X			X
2. Seedling Quality Services 6511 203rd Ave. S.W. Centralia, WA 98531 Contact: Sally Johnson 206/273-9882	X		X	X	X	X		X	X
3. MacMillan-Bloedel Ltd. 65 Front St. Nanaimo, BC V9R 5A9 Contact: Glen Dunsworth 604/753-1112		X	X	X	X	X	X		X
4. Oregon State University* Dept. of Forest Science Corvallis, OR 97331 Contact: Doug McCreary 503/753-9166					X	X	X		

*This OSU service will no longer be offered after the 1985/86 testing season.

TISSUE NUTRIENT ANALYSES*

5. Oregon State University
   Soil Science Department
   Plant Analysis Laboratory
   Corvallis, OR 97331
   Contact:
   Dean Hanson 503/754-2441

6. Oregon State University
   Horticulture Department
   Corvallis, OR 97331
   Contact:
   Jim Wernz 503/754-3695

7. Chinook Research Laboratories
   333 N. Santiam Hwy.
   Lebanon, OR 97355
   Contact:
   John Burnett 503/259-2488

8. Western Laboratories, Inc.
   P. O. Box 400
   Parma, ID 83660
   Contact:
   John Taberna 208/722-6564

9. Soil and Plant Laboratory, Inc.
   P. O. Box 1648
   Bellevue, WA 98009
   Contact:
   Dirk Muntean 206/746-6665

* Note: This is a partial list of PNW and Intermountain analytical laboratories. Nearly every land-grant university will have one or more labs. Readers are encouraged to learn of other facilities in their respective states.

SAMPLING AND SHIPPING

A full battery of vigor tests will require 120-150 seedlings. Samples should be representative of the lot as a whole. Depending on the time of year and reason for the test, seedlings can be sampled directly from the nursery bed, the grading line, cold storage or planting site. More than one sample is recommended for seedling lots that occupy large areas in the nursery. The user's judgement is important in determining what constitutes a representative sample.

Seedling samples should be promptly refrigerated (between 2° and 10° C) and transported to the test location. Samples taken from storage should also be kept cool. Warm temperatures for prolonged periods can reduce seedling vigor. Seedlings can be shipped in heavy-duty, wax-coated cardboard boxes or ice chests via a commercial bus, the United Parcel Service, or personal delivery. Since there is always the likelihood of transport problems (such as a seedling lot sitting in a warm bus depot overnight), it is adviseable to notify someone at the test facility that you are sending seedlings and when to expect them. Same day or overnight delivery is preferred.

As a final note, seedling shipments should be scheduled so that weekend deliveries are avoided (unless prior arrangements have been made). Maintaining a close working relationship with the test facility will pay off in more prompt and reliable service and results.

CONCLUSION

The potential benefit of seedling quality testing is very high relative to the cost. Although enough data exist to demonstrate the usefulness of these tests, there is still a need for more complete information about the interaction between seedling quality attributes and site-specific conditions. For example, which seedling traits are most important on droughty sites?, or on moist coastal sites where competing vegetation is the limiting factor? Aside from the seedling aspect, it is also important that a forester be able to determine or predict accurately the growth limiting factors on a site.

Acquiring new knowledge about seedling quality testing will require a close working relationship between the nursery manager, forester and vigor test personnel. As more experiments and field trials confirm and fine-tune the usefulness of these tests, the more the procedure will become a routine part of regeneration practices. On an historical note, when Wakely (1954) proposed morphological grades for culling seedlings, there was undoubtedly reluctance on the part of many nursery managers to discard seedlings simply because they were small. Now morphological grading is a routine practice.

ACKNOWLEDGEMENT

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REFERENCES

Burdett, A. N. 1979. A non-destructive method for measuring the volume of intact plant parts. Can. J. For. Res. 9:120-122.

Duryea, M. L. 1985. Evaluating seedling quality: Importance to reforestation. In Proc.: Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. L. Duryea, ed.). Workshop held Oct. 16-18, 1984. Forest Res. Lab., Oregon State Univ., Corvallis, OR. pp. 1-4.

Faulconer, J. R. and B. E. Thompson. 1985. Benefits of knowing seedling quality. In Proc.: West. and Intmtn. Nurserymen's Assoc. meeting, August 14-16, 1984, U.S. For. Serv. Gen. Tech. Report INT-185, June 1985, pp. 84-87.

Glerum, C. 1985. Frost-hardiness of coniferous seedlings: Principles and applications. In Proc.: Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. L. Duryea, ed.). Workshop held Oct. 16-18, 1984. Forest Res. Lab., Oregon State Univ., Corvallis, OR. pp. 107-123.

Joly, R. J. 1985. Techniques for determining seedling water status and their effectiveness in assessing stress. In Proc.: Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. L. Duryea, ed.). Workshop held Oct. 16-18, 1984. Forest Res. Lab., Oregon State Univ., Corvallis, OR. pp. 17-28.

Landis, T. K. 1985. Mineral nutrition as an index of seedling quality. In Proc.: Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. L. Duryea, ed.). Workshop held Oct. 16-18, 1984. Forest Res. Lab., Oregon State Univ., Corvallis, OR. pp. 29-48.

Lavender, D. P. 1985. Bud dormancy. In Proc.: Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. L. Duryea, ed.). Workshop held Oct. 16-18, 1984. Forest Res. Lab., Oregon State Univ., Corvallis, OR. pp. 7-16.

McCreary, D. D., and M. L. Duryea. 1985. OSU vigor test: Principles, procedures, and predictive ability. In Proc.: Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. L. Duryea, ed.). Workshop held Oct. 16-18, 1984. Forest Res. Lab., Oregon State Univ., Corvallis, OR. pp. 85-92.

Ritchie, G. A. 1985. Root growth potential: Principles procedures and predictive ability. In Proc.: Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. L. Duryea, ed.). Workshop held Oct. 16-18, 1984. Forest Res. Lab., Oregon State Univ., Corvallis, OR. pp. 98-105.

Ritchie, G. A. 1984. Assessing seedling quality. In: Forest Nursery Manual: Production of bareroot seedlings (M. L. Duryea and T. D. Landis, eds.), Martinus Nijhoff/Dr. W. Junk Publishers, for For. Res. Lab., Oregon State Univ., Corvallis, OR. pp. 243-259.

Thompson, B. E. 1985. Seedling morphological evaluation -- What you can tell by looking. In Proc.: Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. L. Duryea, ed.). Workshop held Oct. 16-18, 1984. Forest Res. Lab., Oregon State Univ., Corvallis, OR. pp. 59-71.

Wakeley, P. C. 1951. Planting the southern pines. USDA For. Serv., S. E. For. Exp. Stn. Occ. Paper 122. 579 p.

When to Measure Seedling Quality in Bareroot Nurseries[1]

David G. Simpson[2]

Abstract.--Quality of bareroot conifer nursery stock is measured (1) during the growing phase, (2) before lifting, and (3) before outplanting. The appropriate tests to make at each times are discussed.

Seedling quality can be described or measured using a wide range of techniques and procedures (Burdett 1983; Chavasse 1980; Ritchie 1984). The rationale for assessing seedling quality, in particular, the principles and procedures for those seedling quality tests presently used on an operational basis are summarized in Ken Munson's paper (this proceedings).

The purpose of my paper is to discuss which, and perhaps more importantly, when are these seedling quality tests used in bareroot nurseries. In the bareroot seedling production cycle, there are three phases when seedling quality tests are used: (1) during the growing season, (2) prior to lifting, and (3) prior to field planting.

[1]Paper presented at the Intermountain Nurserymen's Association meeting, August 13-15, 1985, Fort Collins, CO.

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MEASURES MADE DURING THE GROWING SEASON

Measurement of seedling quality, particularly seedling material attributes (Ritchie 1984) during the growing season, can help the nurseryman produce a maximum number of saleable seedlings. Morphological measurements of height, stem diameter and dry weights when taken at intervals over a growing season can be used to generate growth curves (fig. 1) for crops. These curves, when repeated for several years, can provide a reasonable prediction of crop inventories. As well, "fine tuning" of fertilizer, root culturing and irrigation regimes can be made so that the maximum number of target quality seedlings are produced.

In British Columbia, tissue nutrient levels (N:P:K:Ca:Mg) of 1+0 Douglas-fir (coastal and interior varieties), white spruce, lodgepole pine and Sitka spruce have been determined annually in mid-October since 1968 (van den Driessche 1984). The results of these tests when considered along with the size of the 1+0 seedlings, the target sizes of the 2+0 crop and the "normal" nutrient levels for a particular species x nursery combina-

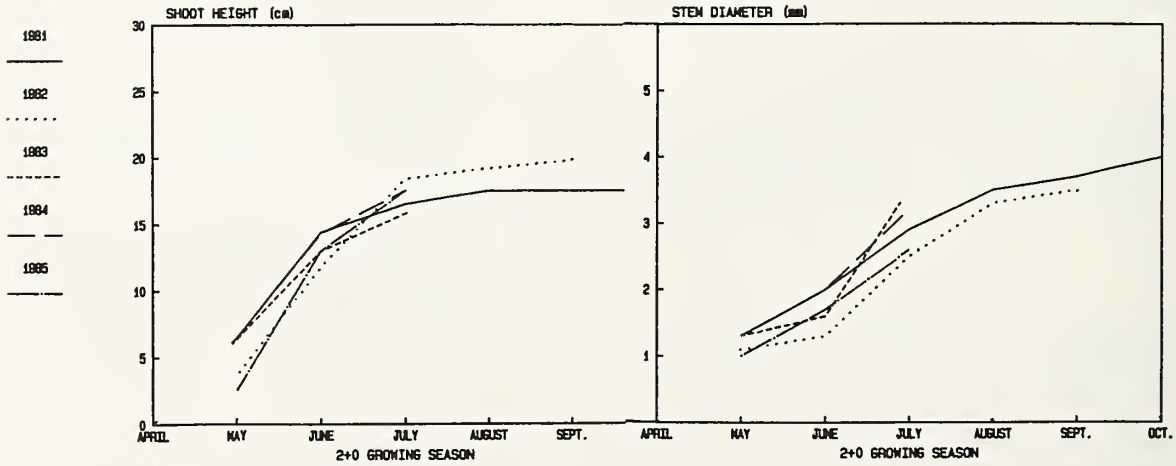

Figure 1.--Shoot height and stem diameter growth of 2+0 interior spruce bareroot seedlings at Skimikin Nursery, Salmon Arm, B.C. Each sample point represents 200 to 250 seedlings.

tion are used to develop the fertilizer regime for the second growing season.[3] Nutrient analysis during the growing season is usually used to determine if deviations in projected growth rates, or physical abnormalities, such as chlorosis, are nutrient-related.

For operational use, the most common means to assess plant moisture stress is to measure xylem pressure potential (XPP) using the pressure chamber method (Cleary and Zaerr 1980; Ritchie and Hinckley 1975; Waring and Cleary 1967). Moisture stress applied during the growing season has been reported to result in growth reductions in several conifer species (Dykstra 1974; Glerum and Pierpoint 1968; Kaufmann 1977; Schulte and Marshall 1983; Timmis and Tanaka 1976; Young and Hanover 1978). The effectiveness of plant moisture stress as a cultural tool to manipulate seedling growth may interact with daylength. Blake et al. (1979) noted that mild moisture stress (pre-dawn xpp of -0.4 to -0.8 MPa) was most effective in reducing shoot:root ratios and apical height growth, while increasing root mass and stem diameter if the stress was applied in mid-July before natural daylengths shortened. Moisture stress may also be a useful cultural tool in the "hardening" process, particularly with those conifers indigenous to regions with mid-summer drought, which do not respond quickly to shortening daylengths, or are grown in nurseries with longer daylengths (Lavender 1985). Young and Hanover (1978) found dormancy could be imposed using water stress in Colorado blue spruce, even under 24-hour days; however, this imposed dormancy (quiescence) was released on re-watering. Proleptic, or lammas growth in Douglas-fir can also be limited by water stress (Blake et al. 1979).

With the exception of cold hardiness determinations, performance attributes (Ritchie 1984) are not usually measured during the growing season. Nurseries experiencing frosts early or late into the growing seasons often undertake cold hardiness testing to determine if irrigation for frost protection is required.

MEASURES MADE PRIOR TO LIFTING

Seedling quality assessments made at this time are done so for two reasons: (1) to describe the stock quantity and quality for the nursery customer, and (2) to ensure seedlings destined for cold/frozen storage are lifted at a time of maximum "storability".

Material attributes, such as standard morphological assessments, and in some cases, special measurements of resting bud gross morphology (Thompson 1985) or needle primordia number (Colombo and Odlum 1984; Colombo et al. 1982) are appropriately measured at this time. Tissue nutrient analysis can be done as there may be field performance benefits obtained from increased tissue nutrient levels (Landis 1985). Moisture stress (XPP) at lifting can have adverse effects on field performance of stored seedlings (Daniels 1978). Monitoring of XPP using the pressure chamber method (Cleary and Zaerr 1980; Ritchie and Hinckley 1975; Waring and Cleary 1967) during the lifting period would seem a worthwhile process to minimize the stresses associated with lifting, sorting and grading of nursery stock (Burdett and Simpson 1984).

Choice of lifting date can be based on a number of factors: operational considerations, such as staff availability and nursery field access; past experience, or "lifting windows" for specific seedlot x nursery combinations (Jenkinson 1984); or some measure of seedling physiology (Burdett and Simpson 1984) which predicts post-storage vigor or field performance potential. It is immaterial which means of deciding on a lifting date is used so long as the method(s) selected ensure the seedlings provided to the customer at planting time will survive and grow.

In British Columbia, past experience too often has been found to be an unreliable means of determining a lifting date to ensure optimum post-storage seedling vigor. The lifting window method (Jenkinson 1984) used with apparent success in California and the chilling hour accumulation methods used in Ontario (Mullin and Hutchinson 1978) have not been widely used in British Columbia principally because of the large number (>1500) of seedlots and species (17) grown in our nurseries. The wide geographic (48.5 to 60°N and 114 to 139°E) and considerable elevational range (0-2000 m) of seed origins would require considerable effort to generate seed source lifting windows. Thus, it was for both practical and philosophical reasons that research effects were directed towards consideration of several physiological variables which may predict post-storage because of a direct causal relationship, or simply by correlation.

Dormancy and tissue cold hardiness appear to be the most useful performance attributes measurable prior to lifting (Garber and Mexal 1980; Burdett and Simpson 1984). Several techniques to measure dormancy have been used, and are reviewed by Lavender (1985) and Ritchie (1984). Mitotic activity of meristematic shoots (buds), a material attribute, may be a useful tool for predicting when to lift conifer seedlings as Carlson et al. (1980) observed a reduction of mitotic activity in Douglas-fir as fall progressed. Further research is needed, however to ascertain the predictive value of pre-lift mitotic activity measurements as a means of deciding when to lift to overwinter storage. Dormancy release index (Ritchie 1982, 1984; Ritchie and Dunlap 1980) also may be a useful tool in choosing lifting dates. Dormancy release index measurement, however, requires 10 to 60 days. This time requirement limits the practical application of the technique.

Cold hardiness has been implicated as being correlated with seedling storability and thus may be useful in choosing lifting dates (Burdett and Simpson 1984). Several methods of measuring

[3]Maxwell, J. 1985. Personal conversation. B.C. Ministry of Forests, Silviculture Branch, Surrey, B.C., Canada.

tissue cold hardiness are available and have been amply reviewed by Glerum (1985), Ritchie (1984), Timmis (1976) and Warrington and Rook (1980). Presently in British Columbia, an operational pre-lifting cold hardiness testing program has sampled seedlings from nearly 25 nurseries. The test utilizes a controlled freeze at 6°C hr^{-1} to -18°C followed in 4 to 10 days by an assessment of foliage mortality. If foliage mortality due to the freezing test is less than 25%, seedlings are judged suitable for lifting to overwinter (ca. 4 to 8 months) frozen (-2°C) storage. The accuracy of the lifting recommendations are checked by determining root regeneration potential after 6 months, -2°C cold storage. In Ontario, an electrical conductivity method (Colombo et al. 1984) of measuring cold hardiness is used to determine if seedlings are sufficiently hardy to overwinter out-of-doors. These conductivity methods, along with the more rapid differential thermal analysis (DTA) technique (Becwar et al. 1981; Sakai 1979, 1982; Wallner et al. 1982) are presently being evaluated as quicker (6 to 48 hours) methods of assessing cold hardiness such that safe lifting dates can be selected.

MEASURES PRIOR TO PLANTING

Fall and winter lifted seedlings that receive overwinter cold storage may exhibit moisture stress in storage if lifted when under moisture stress, packaged incorrectly such that tissue water is lost, or subject to temperature fluctuations during the storage period so that water condenses on the inside of the multi-wall liner bags. The pressure chamber technique has proved a useful monitoring tool to ensure proper lifting, storage and handling practices are followed. In my experience, it is very rare to find overwinter stored seedlings with XPP levels less than -0.5 MPa unless gross mishandling has occurred. On the planting site, however, bareroot seedlings are susceptible to moisture loss during the handling process which may impede growth (Coutts 1982). Using the pressure chamber on the planting site can serve to educate field staff as to their handling effects on seedling water relations. It should be noted, however, that whole plant XPP may not be a sensitive enough measure to detect damage to fine roots (Coutts 1981).

Presently, there are only two performance attributes which are used to measure seedling quality at, or shortly before, planting. The vigor test developed at Oregon State University (Hermann and Lavender 1979) has been shown (McCreary and Duryea 1985) to be well correlated with field survival. Unfortunately, in many circumstances, the 30 days required for damage to develop limits the usefulness of this test. Root growth potential (RGP) testing (Ritchie 1985) using a variety of test conditions and durations has shown generally strong correlation to field performance (Day 1982; Sutton 1980, 1983; Burdett 1979; Burdett et al. 1983; Ritchie and Dunlap 1980). Ritchie (1985) describes the tests developed by Stone and his colleagues (Stone 1955; Stone and Schubert 1959(a), 1959(b); Stone and Jenkinson 1970). The standard RGP test requires 28 days; in British Columbia, a 7-day test period has been found adequate for growth of large numbers of new roots in most species x stock types. The RGP test conditions are somewhat arbitrary, but should be chosen such that (1) the strongest correlations with field performance are obtained, and (2) the best differentiation between low and medium vigour stock is attained. For lodgepole pine, 30°C day/25°C night temperature regimes and a 16-hour day with a photosynthetic photon flux density (PPFD) of 400 mol $s^{-1}m^{-2}$ seem to produce the most number of new roots (Burdett 1979), while for white spruce and Douglas-fir, cooler regimes appear to result in greater numbers of new roots (figs. 2 and 3). Present operational practice in British Columbia is to use the warmer 30°C/25°C regimes for all species as satisfactory correlation between RGP and field performance has been demonstrated in our major species (spruce, lodgepole pine, Douglas-fir) (Burdett et al. 1983; Simpson unpubl. data) at these temperatures, and all species grown in British Columbia have been observed to produce roots at these temperatures. Research underway may, however, result in changes to these conditions in the future if better correlation with field performance and/or better differentiation of low and medium vigour seedlots can be obtained.

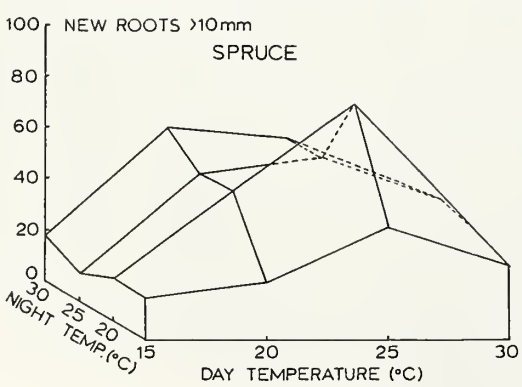

Figure 2.--Day/night temperature regime effects on root growth potential (RGP) of Engelmann spruce container-grown seedlings. Each sample point represents the mean number of new roots >10 mm in a 16-seedling sample.

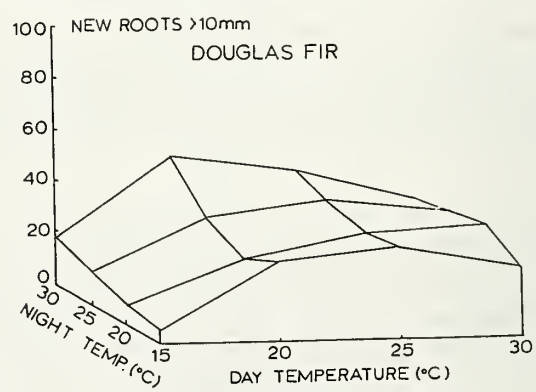

Figure 3.--Day/night temperature regime effects on root growth potential (RGP) of Douglas-fir (interior variety) container-grown seedlings. Each sample point represents the mean number of new roots >10 mm in a 16-seedling sample.

SUMMARY

In bareroot nurseries, seedling quality should be measured using the appropriate tests and during the appropriate phases of the production cycle, these are:

Production phase	Quality test	Operational objective(s)
Growing	- Morphology	- Production targets from curves
	- Nutrient levels	- Ensure maximum growth rates - Avoid deficiencies/excesses
	- PMS	- Ensure maximum growth rates - Dormancy induction
	- Cold hardiness	- Frost protection
Pre-lifting	- Morphology	- Stock descriptions
	- Nutrient levels	- Possible correlation to field performance
	- PMS	- Avoid stress at lifting
	- Dormancy status	- Predict storability
	- Cold hardiness	- Predict storability
Pre-planting	- PMS	- Avoid storage and handling stress
	- Vigour test	- Correlated with field performance
	- RGP	- Correlated with field performance

ACKNOWLEDGMENT

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LITERATURE CITED

Becwar, M.R., C. Rajashekar, K.H. Hanson-Bristow and M.J. Burke. 1981. Deep undercooling of tissue water and winter hardiness limitations in timberline flora. Plant Physiol. 68:111-114.

Blake, J., J. Zaerr and S. Hee. 1979. Controlled moisture stress to improve cold hardiness and morphology of Douglas-fir seedlings. For. Sci. 25:576-582.

Burdett, A.N. 1979. New methods for measuring root growth capacity: their value in assessing lodgepole pine stock quality. Can. J. For. Res. 9:63-67.

Burdett, A.N. 1983. Quality control in the production of forest planting stock. For. Chron. 59:132-138.

Burdett, A.N. and D.G. Simpson. 1984. Lifting, grading, packaging, and storing. In Forest nursery manual: Production of bareroot seedlings (Duryea and Landis, eds.) Nijhoff/Junk Publ. for For. Res. Lab., O.S.U., Corvallis, Ore. pp. 227-234.

Burdett, A.N., D.G. Simpson, and C.F. Thompson. 1983. Root development and plantation establishment success. Plant and Soil 71:103-110.

Carlson, W.C., W.D. Binder, C.O. Feenan and C.L. Preisig. 1980. Changes in mitotic index during onset of dormancy in Douglas-fir seedlings. Can. J. For. Res. 10:371-378.

Chavasse, C.G.R. 1980. Planting stock quality: a review of factors affecting performance. N.Z.J. For. 25:144-171.

Cleary, B.D. and J.B. Zaerr. 1980. Pressure chamber techniques for monitoring and evaluating seedling water status. N.Z.J. For. Sci. 10:133-141.

Colombo, S.J. and K.D. Odlum. 1984. Bud development in the 1982-83 overwintered black spruce container seedling crop. Ont. Min. Nat. Resources For. Res. Note 38. 4 p.

Colombo, S.J., C. Glerum and D.P. Webb. 1982. Bud development in black spruce container stock. Ont. Min. Nat. Resources For. Res. Note No. 32. 5 p.

Colombo, S.J., D.P. Webb and C. Glerum. 1984. Frost hardiness testing: an operational monitoring manual for use with extended greenhouse culture. Ont. Min. Nat. Resources For. Res. Rep. No. 110. 14 p.

Coutts, M.P. 1981. Water relations of Sitka spruce seedlings after root damage. Ann. Bot. 49:661-668.

Coutts, M.P. 1982. Effects of root or shoot exposure before planting on water relations, growth, and survival of Sitka spruce. Can. J. For. Res. 11:703-709.

Daniels, T.G. 1978. The effect of winter plant moisture stress on survival and growth of 2+0 Douglas-fir seedlings. M.S. thesis. Ore. St. Univ., Corvallis, Ore. 86 p.

Day, R.J. 1982. Evaluating root regenration potential of bareroot nursery stock. In Proc. Intermountain Nurserymen's Assoc. Meeting. Can. For. Serv. Infor. Rep. NOR-X-241. pp. 83-86.

Dykstra, G.F. 1974. Drought resistance of lodgepole pine seedlings in relation to provenance and tree water potential. B.C. For. Serv. Res. Note 62. 7 p.

Garber, M.P. and J.G. Mexal. 1980. Lift and storage practices: their impact on successful establishment of southern pine plantations. N.Z.J. For. Sci. 10:72-82.

Glerum, C. 1985. Frost hardiness of coniferous seedlings: principles and applications. In Proc. Evaluating seedling quality: principles, procedures, and predictive abilities of major tests. (M. Duryea, ed.). For. Res. Lab., Ore. St. Univ., Corvallis, Ore. pp. 107-123.

Glerum, C. and G. Pierpoint. 1968. The influence of soil moisture deficits on seedlings growth of three coniferous species. For. Chron. 44:26-29.

Hermann, R.K. and D.P. Lavender. 1979. Testing the vigor of coniferous planting stock. Ore. St. Univ. For. Res. Lab. Res. Note No. 63. 3 p.

Jenkinson, J.L. 1984. Seed source lifting windows improve plantation establishment of Pacific slope Douglas-fir. In Seedling physiology and reforestation success (Duryea and Brown, eds.). Nijhoff/Junk Publ. Dordrecht, The Netherlands. pp. 115-141.

Kaufmann, M.R. 1977. Soil temperature and drought effects on growth of Monterey pine. For. Sci. 23:317-325.

Landis, T.D. 1985. Mineral nutrition as an index of seedling quality. In Proc. Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. Duryea, ed.) Ore. St. Univ. For. Res. Lab., Corvallis, Ore. pp. 29-48.

Lavender, D.P. 1985. Bud Dormancy. In Proc. Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. Duryea, ed.) Ore. St. Univ. For. Res. Lab., Corvallis, Ore. pp. 7-15.

McCreary, D.D. and M.L. Duryea. 1985. OSU vigor test: principles, procedures and predictive ability. In Proc. Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. Duryea, ed.) Ore. St. Univ. For. Res. Lab., Corvallis, Ore. pp. 85-92.

Mullin, R.E. and R.E. Hutchinson. 1978. Fall lifting dates, overwinter storage, and white pine seedling performance. For. Chron. 54:261-264.

Ritchie, G.A. 1982. Effect of freezer storage on bud dormancy release in Douglas-fir seedlings. Can. J. For. Res. 14:186-190.

Ritchie, G.A. 1984. Assessing seedling quality. In Forest nursery manual: Production of bare-root seedlings (Duryea and Landis, eds.) Nijhoff/Junk Publ. for For. Res. Lab., Ore. St. Univ., Corvallis, Ore. pp. 243-259.

Ritchie, G.A. 1985. Root growth potential: principles, procedures, and predictive ability. In Proc. Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. Duryea, ed.) Ore. St. Univ. For. Res. Lab., Corvallis, Ore. pp. 93-105.

Ritchie, G.A. and J.R. Dunlap. 1980. Root growth potential: its development and expression in forest tree seedlings. N.Z.J. For. Sci. 10: 218-248.

Ritchie, G.A. and T.M. Hinckley. 1975. The pressure chamber as an instrument for ecological research. Advances in Ecological Res. 9:165-254.

Sakai, A. 1979. Freezing avoidance mechanism of primordial shoots of conifer buds. Plant and Cell Physiol. 20:1381-1390.

Sakai, A. 1982. Extraorgan freezing of winter buds of conifers. In Plant cold hardiness and freezing stress. Vol. 2 (P.H. Li and A. Sakai, eds.). Academic Press, NY. pp. 199-209.

Schulte, P.J. and P.E. Marshall. 1983. Growth and water relations of black locust and pine seedlings exposed to controlled water stress. Can. J. For. Res. 13:334-338.

Sutton, R.F. 1980. Planting stock quality, root growth capacity, and field performance of three boreal conifers. N.Z.J. For. Sci. 10:54-71.

Sutton, R.F. 1983. Root growth capacity: relationship with field root growth and performance in outplanted jack pine and blue spruce. Plant and Soil 71:111-122.

Stone, E.C. 1955. Poor survival and the physiological condition of planting stock. For. Sci. 1:90-94.

Stone, E.C. and J.L. Jenkinson. 1970. Influence of soil water on root growth capacity of ponderosa pine transplants. For. Sci. 16:230-239.(cited by Ritchie 1985).

Stone, E.C. and G.H. Schubert. 1959(a). Seasonal periodicity in root regeneration of ponderosa pine transplants -- a physiological condition. Proc. Soc. Amer. Foresters. pp. 154-155. (Cited by Ritchie 1985).

Stone, E.C. and G.H. Schubert. 1959(b). The physiological condition of ponderosa pine (Pinus ponderosa Laws.) planting stock as it affects survival after cold storage. J. of Forestry 57:837-841. (Cited by Ritchie 1985).

Thompson, B.E. 1985. Seedling morphological evaluation - what you can tell by looking. In Proc. Evaluating seedling quality: principles, procedures and predictive abilities of major tests (M. Duryea, ed.) Ore. St. Univ. For. Res. Lab., Corvallis, Ore. pp. 59-71

Timmis, R. 1976. Methods of screening tree seedlings for frost hardiness. In Tree Physiology and Yield Improvement. (Cannell and Last, eds.) Academic Press, NY. pp. 421-435.

Timmis, R. and Y. Tanaka. 1976. Effects of container density and plant water stress on growth and cold hardiness of Douglas-fir seedlings. For. Sci. 22:167-172.

van den Driessche, R. 1984. Soil fertility in forest nurseries. In Forest nursery manual: Production of bareroot seedlings (Duryea and Landis, eds.) Nijhoff/Junk Publ. for For. Res. Lab., Ore. St. Univ., Corvallis, Ore. pp. 63-74.

Wallner, S.J., J.E. Bourque, T.D. Landis, S.E. McDonald and R.W. Tinus. 1982. Cold hardiness testing of container seedlings. In Proc. 1981 Intermountain Nurserymen's Assoc. Meeting. Can. For. Serv. Info. Rep. NOR-X-241. pp. 21-25.

Waring, R.H. and B.D. Cleary. 1967. Plant Moisture Stress: evaluation by pressure bomb. Science 155:1248-1254.

Warrington, I.J. and D.A. Rook. 1980. Evaluation of techniques used in determining frost tolerance of forest planting stock: a review. N.Z.J. For. Sci. 10:116-132.

Young, E. and J.W. Hanover. 1978. Effects of temperature, nutrients and moisture stresses on dormancy of blue spruce seedlings under continuous light. For. Sci. 24:458-467.

How to Use Seedling Quality Measurement in Container Nurseries[1]

C. J. Sally Johnson[2]

Abstract--The various techniques for measuring seedling quality are discussed in relation to the time of testing. How the data thus gathered can be applied to cultural practice alternatives is also discussed with a common sense approach to growing seedlings.

There is a wide range of seedling quality tests available and these have been discussed quite adequately elsewhere (Burdett 1983, Chavasse 1980, Ritchie 1984). The procedures for these tests are covered in Ken Munson's paper (pp 71-77).

The purpose of this paper is to discuss how to use the data gained from these tests over the life of a crop to produce a better seedling.

MEASURES MADE DURING THE GROWING SEASON

Morphological measurements which consist of height, caliper, shoot and root dry weights and--late in the season--bud heights can generate growth curves over time and provide an indicator of how well your crop is doing in meeting size specifications required by your customers. Water and nutrient regimes can be used to increase or decrease growth as needed during the growing season. You need to keep in mind time and climate constraints. The unwise practice of extending the active growth of seedlings into the late fall and early winter could have some disastrous effects on your crop. Top growth must cease early enough to allow bud development in later summer. Good bud development requires short days and warm temperatures. If active top growth is continued into September, there will not be enough warm temperatures to ensure proper bud development after the cessation of growth. Root development also takes place in the fall and again, if top growth is extended, the gains in seedling height will be made at the expense of root development. Root dry weights can continue to increase through October and if the height growth has ceased in August, good root mass is the result.

Very little has been written on minimum specifications for root mass and bud size, but experience and common sense can give some indication of where to start. Root dry weights of .40 grams in Douglas fir grown in a 2.0 cubic centimeter container are adequate or better. This root mass will hold its configuration when extracted and provide adequate or better root growth capacities when there are no physiological problems present such as disease. Root dry weights of .30 grams or less usually do not maintain their integrity and generally have lower root growth capacities. Seedlings with finer root systems such as spruce, hemlock and cedar have an adequate root mass at .30 grams. Bud heights in Douglas fir are adquate at 4.0 centimeters. This is measured from the base of the bud where the bud scales begin to the top of the bud. Buds less than four centimeters tall tend to be poorly developed and are usually less frost-hardy than larger buds. Bud heights indicate growth potential for the following year and thus are very important to your customers.

Determining the nutrient levels of tissue is a very important tool for the container grower. The opportunity is there to get rapid results by altering the nutrient regime according to seedling needs for either more or less growth. Each grower needs to establish a nutrient regime suitable for his particular species, the geographical origin of stock, the container sizes and the geographical location of his facility. All of these things will affect the growth of the crop. It is best to use a reputable lab which will provide the expertise in interpreting the nutritional data in the beginning. Later, after the grower has gained some experience with his particular situation, he can prepare his own fertilizer prescriptions. One caution to remember in designing nutrient regimes is that what may work for one grower with his unique combination of species, stock types and geographical location may not work for another.

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Most growers use some form of moisture stress treatment to induce dormancy at the end of the growing season. The most common method of measuring plant moisture stress (PMS) is the pressure chamber method (Cleary and Zaerr 1980; Ritchey and Hinckley 1975). On the other hand, high levels of PMS during the growing season will reduce seedling size. The pressure bomb can be used to keep PMS levels low during the period of active growth and then keep the PMS levels high enough to induce dormancy, but not so high that damage is done to the seedlings. Many growers rely on block weights to determine the need for irrigation both during active growth and the hardening-off phase. This method requires considerable experience in determining how to irrigate by the weight of various-sized blocks. Block weights can vary depending on the consistency of the media, size of seedlings and several other factors. The PMS measurements are a more direct measurement of the moisture status of the seedlings.

MEASURES MADE PRIOR TO LIFTING

This is the time when the finished product is checked for overall quality to ensure that the seedlings are ready for the stresses of storage and outplanting and thus have a good chance of surviving in the field.

Morphological characteristics are the most commonly used measures of seedling quality employed at the time of packing. Almost all seedlings must meet predetermined height and caliper standards to be considered saleable. Although these attributes have failed to predict field survival in the past as accurately as we need, they are still important, and we need to continue to use these attributes as a measure of seedling quality. In order to better predict successful plantation establishment, we need to add more morphological attributes as well as some physiological attributes that are to be discussed later. The morphological attributes we need to add to our specifications are bud height and root dry weight. These two attributes will ensure we have good enough bud and root development to ensure good growth and survival in the field, which are critical for good plantation establishment. There are other methods for measuring these attributes and these are discussed in Dave Simpson's paper (pp 78-83). The bud heights and root dry weights, however, are the simplest methods being used operationally at this time. These are also specifications that can be given a number and written into the seedling growing contract.

There are various methods of determining the best time to lift seedlings for storage (lifting window) and again, Dave Simpson has discussed these methods more fully. Cold-hardiness is being used operationally for this in a number of areas and is a relatively rapid way to determine readiness for storage (Burdett and Simpson 1984; Glerum 1985). Lifting windows may vary with seed source, species, yearly climate fluctuations and cultural practice regimes. This is, again, a situation where each grower needs to become fa-iliar with how his unique situation affects the lifting window for his stock.

Cold-hardiness levels may also be needed to ensure survival in the field when below freezing temperatures are expected shortly after planting, particularly in the case of fall planting. The situation often arises when seedlings are being grown a considerable distance from the seed origin. For instance, Intermountain seed sources are being grown in the Pacific Northwest. In this case, the frost hardiness development of the seedlings whose origins are in Idaho, but who are hardened off in Oregon will be less than if the seedlings were hardened off in Idaho (Unpublished data, Johnson, 1985). This can cause losses due to cold damage in the field. It is wise to keep this in mind when growing seedlings not from your own seed zone.

MEASURES PRIOR TO PLANTING

Assuming that all seedlings have already been graded for morphological attributes, we now need to determine the physiological state of the seedlings prior to outplanting. Overwinter storage of seedlings can either be in a controlled cooler or freezer or, in many cases, be uncontrolled outside storage. The controlled units are, of course, preferable, as uncontrolled storage usually depends on a snowfall prior to the onset of very cold temperatures to protect seedlings from cold damage. As everyone knows, some years you get the snow and some years you don't. Even controlled storage units can malfunction, allowing the seedlings to experience damaging temperatures. To ensure that no deterioration of stock quality has taken place during the period of storage, a root growth capacity test is in order. Most operational root growth tests available take place in a controlled environment at relatively warm temperatures with an extended photoperiod. The duration of the test is approximately thirty days. Interpreting root growth data is in the initial stages in many areas of the western United States, but we do have enough experience to give some helpful hints for interpreting the test results. Root growth capacity values that may prove satisfactory in Western Washington may not be satisfactory in Colorado. The severity of the planting site will determine what root growth capacity is adequate. Seedlings that produce any new roots at all in the thirty day period have a chance of surviving, given the right conditions. However, seedlings that produce fewer than 30 new roots over one centimeter in length during the test have a poor chance of survival on the dry sites of the San Juan National Forest (Unpublished data, Johnson 1985). The seedlings producing fewer than 11 new roots over one centimeter have a poor chance of survival in the better sites of the Olympic National Forest

in Washington (Unpublished data, Johnson 1985). Experience has also shown that seedlings that fail to produce over 30 new roots over one centimeter during the test usually have something wrong with them. The problem may be inadequate root mass, damaged roots or dead roots due to disease, overwatering, etc. One- to two-year-old seedlings of most, if not all, species of conifers are capable of producing over 50 new roots over one centimeter in length within the 30-day test with a fairly high rate of frequency; therefore, expecting a minimum of 30 new roots over one centimeter is a very realistic goal.

SUMMARY

Seedling quality tests can provide valuable assistance to the grower to produce a quality product that has the best chance of survival and growth in the field. The recommended tests can best be utilized as follows:

Operation	Test	Objective(s)
Growing	-Morphology	-Meet targets from growth curves
	-Nutrient levels	-Ensure maximum growth rates -Avoid deficiencies/toxic levels
	-PMS	-Ensure maximum growth rates -Induce dormancy
Pre-lifting	-Morphology	-Desirable stock with set specifications
	-Cold-hardiness	-Predict storability
Pre-planting	-Root growth capacity	-Correlate to field performance

LITERATURE CITED

Burdett, A. N. 1983. Quality control in the production of forest planting stock. For. Chron. 59:132-138.

Burdett, A. N. and D. C. Simpson 1984. Lifting, grading, packaging, and storing. In Forest Nursery manual: Production of bareroot seedlings (Duryea and Landis, eds.) Nijhoff/Junk Publ. For. Res. Lab., O.S.U., Corvallis, OR, pp. 227-234.

Chavasse, C. O. R. 1980. Planting stock quality: a review of factors affecting performance. N. Z. J. For. 25:144-171.

Cleary, B. D. and J. B. Zaerr, 1980. Pressure chamber techniques for monitoring and evaluating seedling water status. N. Z. J. For. Sci. 10:133-141.

Glerum, C. 1985. Frost hardiness of coniferous seedlings: principles and applications. In Proc. Evaluating seedling quality: principles, procedures, and predictive abilities of major tests. (M. Duryea, ed.). For. Res. Lab., O.S.U., Corvallis, OR, pp. 107-123.

Ritchie, G. A. 1984. Assessing seedling quality. In Forest Nursery manual: Production of bareroot seedlings (Duryea and Landis, eds.) Nijhoff/Junk Publ. for For. Res. Lab., O.S.U., Corvallis, OR, pp. 243-259.

Ritchie, G. A. and T. M. Hinckley 1975. The pressure chamber as an instrument for ecological research. Advances in Ecological Res. 9:165-254.

How to Determine Fertilizer Rates and Application Timing in Bareroot Forest Nurseries[1]

T. D. Landis and J. W. Fischer [2]

Abstract.--The uptake and utilization of N, P, and K is affected by nutrient characteristics, seedling factors and nursery environment. Fertilization plans should be customized to reflect individual nursery characteristics. Fertilizer application rates can be determined through soil testing or by crop use. Timing of fertilizer applications varies between nutrients based on nutrient characteristics and seedling response.

The use of fertilizer in forest tree nurseries is generally considered to be a routine cultural operation and many nursery managers apply fertilizers on traditional calendar dates according to some general guidelines. Fertilizers supply a significant portion of the mineral nutrients needed for seedling growth, particularly of the major "fertilizer elements": nitrogen (N), phosphorus (P), and potassium (K). Fertilization has been shown to effect both the quantity and quality of seedling growth and, therefore, application of the correct amount of fertilizer at the proper time is critically important to the production of high-quality seedlings.

FACTORS AFFECTING FERTILIZER NUTRIENT UTILIZATION BY TREE SEEDLINGS

The uptake and utilization of mineral nutrients is affected by a variety of factors related to the seedling itself, to the nursery environment, and specific to the individual fertilizer ions.

Seedling Development

All three fertilizer nutrients are required in relatively large amounts by young seedlings but the actual uptake patterns vary. The amount of P stored in the seed is quite limited and therefore supplies of this nutrient are required almost immediately after germination. Armson (1960) studied the uptake patterns of N, P, and K and found that P was rapidly taken up early in the 1+0 growing season and again later in the year (Figure 1A). N and K, on the other hand, have high early uptake rates which gradually drop off during the growing season; this pattern closely follows the pattern for net seedling growth as represented by the net assimilation rate (Figure 1B). These data suggest that P should be made available to the plant both early and late in the growing season whereas N and K should be supplied during periods of seedling growth.

Species of Seedling

Different tree seedlings have different growth characteristics and therefore require mineral nutrients in different amounts. Rapidly-growing pioneer species, such as jack pine (*Pinus banksiana)* and quaking aspen (*Populus tremuloides)*, require lower amounts of fertility (particularly N) than slower-growing spruces or ash (Stoeckeler and Arneman, 1960). Some nursery managers do not add any supplemental fertilizer to the seedbeds of aspen or western larch (*Larix occidentalis)* in an effort to control height growth whereas spruces or true firs are heavily fertilized to force height growth.

Seedbed Density

The number of seedlings growing per unit area of seedbed has a significant effect on their nutrient uptake. Most nursery workers are familiar with the "dished", chlorotic pattern in seedbeds suffering from N deficiency; this condition exists because seedlings in the interior of the seedbed are under more competition and receive relatively less N than seedlings near the edge (Armson and Sadreika, 1979). This effect of seedbed density varies between species, however, as van den Driessche (1984a) found that Douglas-fir *(Pseudotsuga menziesii)* and Sitka spruce *(Picea sitchensis)* were more sensitive than lodgepole pine *(Pinus contorta)*.

Many nursery managers do not appreciate the very high growing density of tree seedlings compared to agricultural crops. If we assume a seedbed density of 25 seedlings per sq.ft. and a field efficiency of 60%, the resultant growing density of 650,000 seedlings per acre would be extremely high, compared to a typical density of 20,000 plants per acre for corn.

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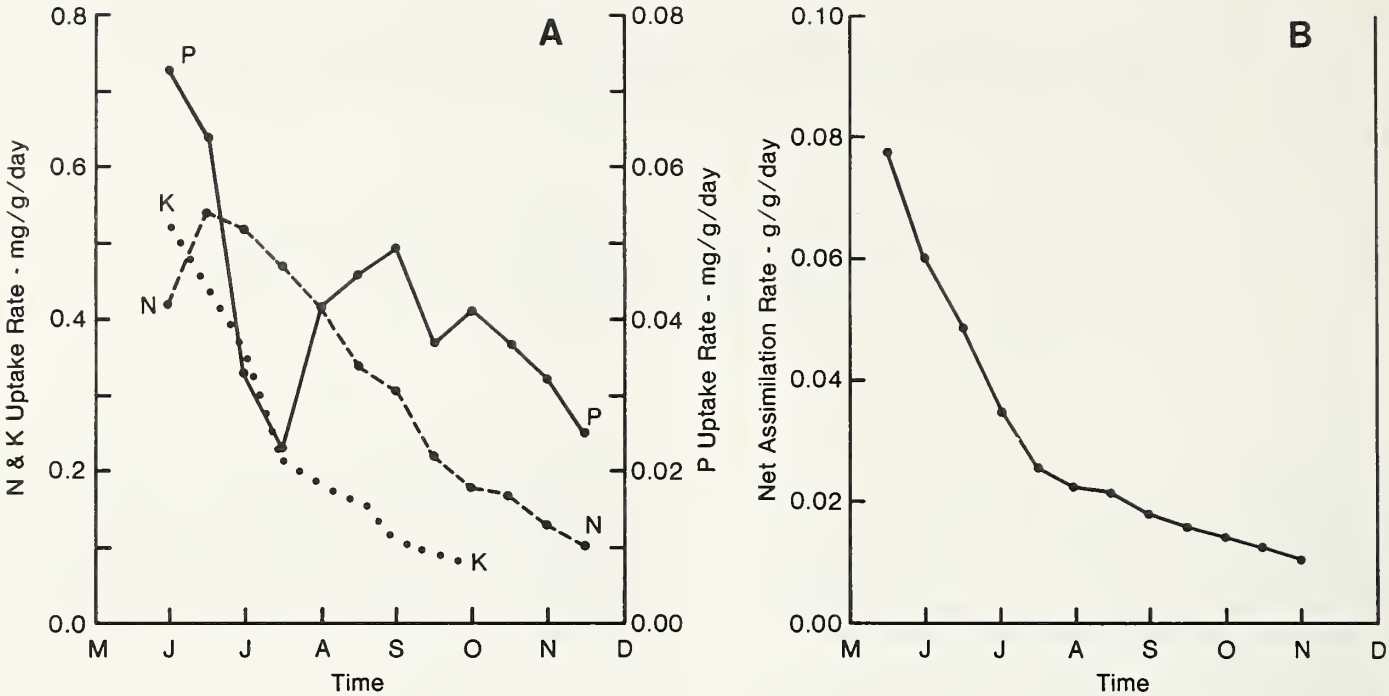

Figure 1.--(A) Comparison of nutrient uptake rates of N, P, and K, with (B) seedling growth rate during the growing season (modified from Armson, 1960).

Temperature

The effect of temperature on nutrient uptake is not surprising but few people realize how significant it can be. A study by van den Driessche (1984b) shows that seedling growth is severely restricted below 10°C, regardless of the level of P fertilization; this growth reduction is very abrupt which suggests that root function is impaired at low temperatures (Fig. 2). Because this is a general physiological effect rather than a specific ion effect, this temperature restriction probably occurs for all mineral nutrients.

Moisture

Soil moisture levels can affect mineral nutrient uptake in several different ways. Nutrient uptake due to mass flow occurs when ions dissolved in the soil solution move with the soil water towards the roots during transpirational uptake. Nutrient absorption is greatest when soil moisture is at field capacity which gives the ideal balance of both water and air. Low soil water content reduces nutrient uptake directly because the resultant low hydraulic conductivity restricts water movement whereas saturated soils reduce nutrient uptake indirectly because the anaerobic conditions adversely affect root and microbial activity.

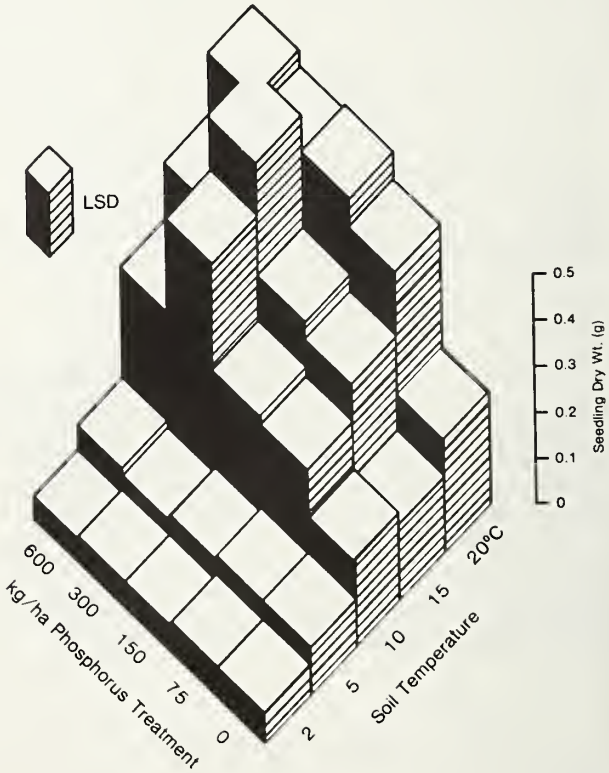

Figure 2.--The effect of soil temperature and phosphorus fertilization rates on Douglas-fir seedling growth (van den Driessche, 1984b).

Table 1.--Characteristics of fertilizer nutrients that influence fertilizer application and timing.

Fertilizer Elements	Nutrient Mobility and Leaching Potential		Time of Peak Nutrient Demand	Fertilizer Application Method	Fertilizer Application Timing
Nitrogen	NO_3^-	High	During rapid growth periods	Top Dressing	At regular intervals (4-5X per season)
	NH_4^-	Medium			
Phosphorus	$P_2O_5^-$	Low	Early and late in growing season	Incorporation or Banding	Pre-sowing
Potassium	K^+	Medium	During rapid growth periods	Incorporation and Top Dressing	Half-presowing and Half-midseason

Characteristics of Individual Fertilizer Ions

Each of the three fertilizer elements acts differently in the soil depending on its electrical charge and other chemical properties. Nitrate (NO_3^-) is a negatively-charged anion and is very mobile in the soil and subject to leaching because anions are not held on the negatively-charged cation exchange sites (CEC). The phosphate ion ($P_2O_5^-$) is also an anion but only about 1% of the total P in the soil is in this available form. Most of the soil P is unavailable because it is usually chemically bound by a number of other ions in the soil and so its mobility and leaching potential are low. K^+ and ammonium -N (NH_4^+) are positively-charged cations that can be bound on the CEC complex; both ions are moderately subject to leaching (Table 1).

These characteristics, in combination with the time of peak nutrient demand, should be considered for both fertilizer application method and timing (Table 1). N fertilizers should be applied as top-dressings at regular intervals throughout the season so that a constant supply of nutrient is available. P is normally applied as a presowing incorporation or banded during sowing to insure that the immobile P ions are available to the young seedlings. K fertilizers are often applied both as an incorporation at the beginning of the season and again as a top dressing about midseason.

WAYS TO ESTABLISH A FERTILIZER APPLICATION PLAN

Every bareroot nursery needs a fertilization plan - a systematic, documented approach describing fertilizer application practices. Each of these plans will be different and will reflect the characteristics of the individual nursery. Most fertilization plans are established using one or more of the following:

1. Personal experience - This is probably the most common and certainly the most traditional way to set up a fertilization program. As in any farming operation, nursery managers can build up a real expertise based on their experiences over the years. In addition to keen powers of observation, nursery workers should have a basic understanding of fertilizer action and soil science in order to learn what works best at their own nursery. The real limitation to this method, however, is the time required to accumulate this experience. Because of the multi-year rotations inherent in tree production, a person must remain at the nursery long enough to witness several different rotations and experience a range of weather and crop variation.

2. Recommendations - This category includes both advice from consultants and recommendations from technical articles and nursery manuals. Nursery consultants are able to visit individual nurseries and learn specifics about soil factors, crop characteristics, and climatic conditions and develop a customized fertilizer program. On the other hand, consultants are expensive and can be addictive - a nursery manager could become overly dependent on outside assistance. Nursery manuals and technical articles usually give "generic" fertilizer recommendations and the nursery manager must be able to modify these recommendations to fit his own conditions and species.

3. Nursery Fertilizer Trials - Undoubtedly the best way to develop a fertilization program is to conduct a series of fertilizer trials right in the nursery so that specific crop responses can be measured. Ideally, trials should be performed on each major soil type and species of seedling, and also should be conducted over several rotations so that all sources of variation can be sampled. Nursery managers should seek the assistance of a statistician or nursery specialist in the planning stages and during the interpretation of nursery fertilization trials.

4. Soil Testing - Most tree nurseries have had soil tests performed at one time or another but many managers are not comfortable with their own interpretation of the test values. Soil tests are a good way to monitor soil fertility and fertilizer response but they have certain limitations. Most tests report in terms of "available" nutrients but these values vary with the extracting solution used in the lab; these extracting solutions supposedly remove the same amount of nutrient that would be available to the tree

seedling. P availability is particularly hard to measure and testing labs across the country use a variety of different extracting solutions which give different P availability values. Although any agricultural soil testing lab can perform soil tests, most are not familiar enough with tree seedlings to provide relevant interpretation of the results. Most published soil fertility standards for tree seedlings have usually developed from fertility trials with one of the major commercial species such as Douglas-fir and may not be applicable to other species of seedlings. Soil testing can also be an expensive operation, especially if the recommended number of samples is taken, so nursery managers should make sure that the cost of the test includes interpretation and recommended fertilizer treatments. Consultants can be very helpful in the interpretation of test results and their fee is usually very worthwhile.

5. Seedling Nutrient Analysis (SNA) - As with soil tests, SNA is expensive but can be invaluable because it is the only real way to determine if the nutrients applied as a fertilizer are ever taken up by the seedling. Interpretation of the test results can be difficult and many of the published standards are ranges of values that may not be sensitive enough to detect a problem with one particular species. Assistance with interpretation is often required and again consultants can be helpful.

CALCULATION OF FERTILIZER APPLICATION RATES

The amount of fertilizer that should be applied to a nursery seedbed can be determined by soil test results or crop use. Maintenance fertilizer applications maintain soil fertility at some target level and are based on soil tests and/or SNA. Replacement applications replace the nutrients used by the seedling crop during the year. P and K are usually applied as maintenance applications using target values for the nutrients (Table 2). Soil N exists in many organic and inorganic forms in nursery soils and there is no widely-accepted test for available N; therefore, N fertilizers are normally applied as replacement applications.

Table 2.--Soil Test Nutrient Targets for Nurseries of the Inland West

Fertilizer Element	Units	Target
Nitrogen (N)		
Total N	%	0.10 to 0.20
Nitrate -N	ppm	25 to 50
Phosphorus (P)[1]		
Available P	ppm	20 to 50
Available P_2O_5	lbs/ac	92 to 230
Potassium (K)		
Available K	ppm	100 to 150
Available K_2O	lbs/ac	240 to 360

[1] Using Olsen's sodium bicarbonate procedure

The type of fertilizer to apply is very important and single element fertilizers (e.g. ammonium sulfate [21-0-0]) are generally recommended so that fertilizer amendments can be directed at a specific nutrient element. Complete fertilizers (e.g. 15-15-15) should not normally be used because there is usually no need to supply N-P-K at the same application. Complete fertilizers are also more expensive than most single element fertilizers. Ammonium phosphates (e.g. 18-46-0) are exceptions because these multi-nutrient fertilizers are sometimes applied as pre-sowing incorporations or in bands during sowing.

Replacement Applications of N

N applications are generally applied based on estimates of crop use because there is no acceptable soil test for available N. van den Driessche (1980) reported that 2+0 conifer crops use from 45-178 lbs/ac (50-200 kg/ac) of N during a rotation. The actual amount of N that a tree seedling crop requires is dependent on species, seedbed density, climate and soil type. Fertilizer nutrient recovery is also relatively low ranging from 13-16% N for a 1+0 crop to perhaps 50% during the 2+0 year (van den Driessche, 1984c). N recommendations vary but some examples from recent nursery manuals are provided in Table 3.

Table 3.--Recommended Nitrogen (N) Application Rates Per Year

Source	Units	Seedlings 1+0	Seedlings 2+0	Transplants X+1
Armson and Sadreika (1979)	lbs/ac	50-200	60-200	40-150
	kg/ha	56-224	67-224	45-168
Aldhous (1975)	lbs/ac	28-100	28-100	45-90
	kg/ha	25-75	25-75	50-100
van den Driessche (1984c)	lbs/ac	0-107	100-147	80-160
	kg/ha	0-120	112-165	90-180
Stoeckeler and Slabaugh (1965)	lbs/ac	40-80	40-80	40-80
	kg/ha	36-71	36-71	36-71

SNA should also be used at the end of the growing season to monitor the actual amount of N that the seedlings are able to take up and this information can then be used to fine-tune fertilizer applications during the following season. SNA can also be used for trouble shooting during the season if nutrient deficiency symptoms such as chlorosis or dished beds become evident. When collecting samples be sure to collect both symptomatic and normal seedlings so that comparisons can be made. Target values for N in conifer needle tissue range from 1.20 to 2.00% (Table 4) which are very broad; each nursery should strive to accumulate enough data to develop standards for their own species.

Table 4.--Standard Values for Mineral Nutrient Concentrations in Conifer Needle Tissue (Landis, 1985)

Mineral Nutrient	Units % dry wt	Adequate Range [1]
Macronutrients		
N	%	1.20 to 2.00
P	%	0.10 to 0.20
K	%	0.30 to 0.80
Ca	%	0.20 to 0.50
Mg	%	0.10 to 0.15
S	%	0.10 to 0.20
Micronutrients		
Fe	ppm	50 to 100
Mn	ppm	100 to 5000
Zn	ppm	10 to 125
Cu	ppm	4 to 12
Mo	ppm	0.05 to 0.25
B	ppm	10 to 100
Cl	ppm	10 to 3000

[1] Macronutrient values are from Youngberg (1984) and micronutrient values from Powers (1974)

Table 5.--Determining Fertilizer Application Rates from Soil Test Results[1]

1. Determine amount of nutrient needed

Target P Level = 35 ppm
\- Soil Test Level = 18 ppm
Need to add as fertilizer = 17 ppm

2. Convert ppm to lbs/ac

$$17 \text{ ppm} = \frac{17 \text{ parts}}{1{,}000{,}000 \text{ parts}} = \frac{17 \text{ lbs}}{1{,}000{,}000 \text{ lbs}}$$

Given: One acre of soil 6" deep (plow-slice) weights 2×10^6 lbs

$$\frac{17 \text{ lbs}}{1{,}000{,}000 \text{ lbs}} = \frac{X}{2{,}000{,}000 \text{ lbs}}$$

X = 34 lbs/ac P

3. Convert from P to P_2O_5

34 lbs/ac x 2.3 = 78.2 lbs/ac P_2O_5

4. Convert to weight of bulk fertilizer

Concentrated superphosphate (0-46-0) contains 46% P_2O_5

$$\frac{78 \text{ lbs/ac } P_2O_5}{0.46} = 169.6 \text{ lbs of 0-46-0 per acre}$$

[1]This same procedure can be used to determine K application rates by substituting 1.2 for 2.3 to convert from K to K_2O in Step 3, and using the appropriate bulk fertilizer conversion in Step 4.

Maintenance Applications of P and K

Soil test targets for P and K are usually given in parts per million (ppm) or pounds per acre (lbs/ac) (Table 2). The ppm units can be converted to amount of fertilizer per acre using the process provided in Table 5. This process uses a standard weight of 4,000,000 lbs for an acre-foot of loam soil (or 2,000,000 lbs/6 in. rooting depth) which is a reasonable approximation and allows the nursery manager to compute the actual amount of fertilizer required to maintain the soil fertility at the desired levels.

Although P fertilizer applications should be computed using the calculations in Table 5, many fertilizer specialists recommend that a starter dose of P be incorporated into the seedbed or banded at the time of sowing regardless of the soil test level. The root system of the newly germinated seedling is very restricted whereas the demand for P is high during seed germination and early seedling growth; these starter applications help insure that a supply of P is readily accessible. van den Driessche (1984c) recommends applying ammonium phosphate (11-55-0) at a rate of 27 lbs/ac (30 kg/ha) in a band 3 to 5 inches below the drill row and reports a substantial increase in growth for spruce seedlings. Unfortunately, most of the standard seed drills used in forest tree nurseries are not equipped for banding although the conversion should not be difficult. An opportunity also exists to use the commercial mycorrhizal applicator manufactured by Whitfield as a band fertilizator applicator; this applicator costs approximately $4500 and is compatible with most nursery seeders (R. A. Whitfield Forestry Manufacturing Co., Mableton, GA).

K fertilization is not normally required in western nurseries because most western soils contain an abundance of K-bearing minerals, particularly in the Great Plains and Intermountain areas. Nursery managers should utilize soil tests, however, to determine the K availability at their own specific nurseries.

SNA should also be used to monitor P and K fertilizer uptake at the end of each growing season or for trouble shooting during the season. General guidelines for the normal range of P and K are given in Table 4; these should be useful until each nursery is able to develop their own standards.

FERTILIZER APPLICATION TIMING

Once the total annual fertilizer application rate has been calculated, the problem of when to apply the fertilizer and the rate per application must be decided. Because of the different characteristics of these three fertilizer nutrients (Table 1), they will be discussed separately.

Nitrogen - This nutrient is normally applied in a series of small applications over the growing

season (Table 6). Because all N fertilizers are water soluble, they are applied as top dressings with standard fertilizer spreaders; N fertilizers can burn succulent seedling foliage and so the fertilizer should be brushed from the foliage or watered-in immediately. The first application of N is usually delayed until after the seedlings have become established because of concern about stimulating damping-off fungi and the possibility of fertilizer burn. During the 2+0 year, however, N fertilizers should be applied as early as possible so that the nutrients are available prior to the first flush of spring growth. Because N is so soluble in the soil, repeat applications may be necessary after heavy spring rains particularly in light-textured soils.

Table 6.--Application Timing of N Top Dressings (Aldhous, 1975 and others)

Crop	Season	Number of Fertilizer Applications: Initial	Subsequent
Seedlings	1+0	5-7 weeks after germination or when primary needles appear	At 3-4 week intervals [1]
	2+0	As early as possible	At 3-4 week intervals [1]
Transplants	X+1	At least 1 month after transplanting	At 4-5 week intervals [1]

[1] Repeat applications may be necessary after heavy rains.

One of the most scientific ways of determining the proper time for N applications is the degree day system which uses accumulated heat units. The degree day approach is attractive because the fertilizer applications are synchronized with seedling growth which, of course, is also tightly linked to temperature. Either ambient or soil temperature can be used as a degree-day basis although soil temperatures are more stable and more accurately reflect the environment where the nutrient uptake is actually occurring. Because of climatic and edaphic variation, each nursery must develop its own degree day system but an example of the degree day schedule used for Ontario nurseries is given in Table 7.

Table 7.--Cumulative Degree Days (1°C basis)[1] can be used to Schedule N Fertilizer Applications (Armson and Sadreika, 1979)

Application No.	Southern Ontario: Jack and Scots Pine	Southern Ontario: Others	Northern Ontario: Jack Pine	Northern Ontario: Others
1	55	55	55	55
2	440	220	330	165
3	1100	440	660	330
4	1650	1100	1320	495
5	--	1650	1760	660
6	--	2310	--	990
7	--	--	--	1430
8	--	--	--	1870

[1] Although not specified, these values are presumably air temperatures.

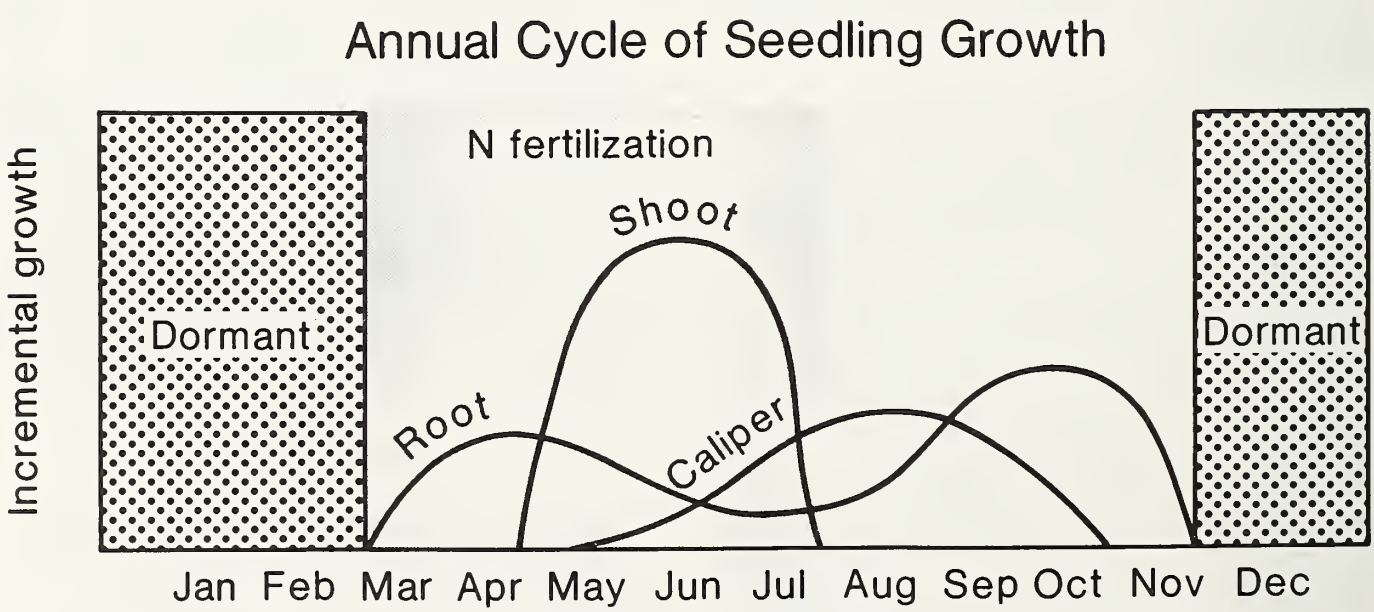

Figure 3.-- Nitrogen (N) fertilization should be scheduled early in the growing season during the period of rapid growth.

If a degree day schedule is not available, the next best procedure is to schedule N fertilizer applications based on seedling growth curves. Plots of growth increments (Fig. 3) show the times when growth generally occurs and so fertilizer applications can be scheduled at regular intervals during this period. This approach insures that the fertilizer is available during the time of maximum seedling growth rather than later in the year when the fertilizer would be wasted or could adversely affect the onset of dormancy or frost hardiness.

Phosphorus - P applications can be applied during the fallow year or prior to sowing so that the nutrient is available early in the growing season (Table 1); these presowing applications are effective because of the immobility of P in the soil. Fallow year applications are applied to the cover or green manure crop so that the P can be fixed into the organic matter and slowly released in subsequent growing seasons. Many soil scientists feel that P is best applied immediately before or at the time of sowing to minimize the potential for chemical immobilization. P uptake is temperature dependent (Fig. 2) and so it is important that adequate supplies are available during the early spring. Mycorrhizae are very important in the P nutrition of tree seedlings and many young seedlings do not become mycorrhizal until late in the 1+0 season, especially in fumigated seedbeds; this early mycorrhizal deficiency is further justification for presowing P applications. Banding P fertilizers below the seed is especially effective and is discussed in the section on P application rates.

Potassium - K is moderately mobile in the soil and is required during periods of active growth and can therefore be applied as either a top dressing or incorporated (Table 1). Leaching losses are more serious in sandy soils with a low CEC so frequent top dressings would be more appropriate under these conditions. Probably the most practical procedure would be to apply half the annual amount as a presowing incorporation and the other half as a midseason top dressing.

CONCLUSIONS AND RECOMMENDATIONS

The utilization of fertilizer nutrients by tree seedlings is affected by many factors including seedling development, species of seedling, seedbed density, soil temperature, and soil moisture. The characteristics of the individual fertilizer elements (N, P, and K) also affects their availability and utilization in nursery soils.

All bareroot nurseries should develop a fertilization plan which is a systematic, documented approach to fertilizer use. Fertilization plans must be developed specifically for individual nurseries to reflect unique climatic and edaphic characteristics and the response of individual seedling species. These plans can be developed using several different procedures: personal experience, recommendations, nursery fertilizer trials, soil testing and seedling nutrient analysis. Ideally, nursery managers will use a combination of all 5 of these procedures to produce a balanced fertilization plan. These plans are not permanently fixed, however, and managers must be flexible enough to accommodate new information into their fertilization plans.

Fertilizer application rates can be determined by soil testing or crop use. Both P and K are applied based on soil test results: the amount of nutrient that is required to bring the soil level up to a target level is calculated and then maintenance applications of fertilizer are used to make up the deficiency. Because there is no practical soil test for available N in nursery soils, replacement applications of N fertilizer are generally applied to replace the N used by the seedlings during the year.

The timing of fertilizer applications is also different for each of the fertilizer elements. N is normally applied as a series of top dressings during the growing season. Degree days or seedling growth curves can be used to synchronize N applications with periods of active seedling growth. P is normally applied during the fallow year, incorporated into the seedbed prior to sowing, or banded during sowing so that adequate P is available during the early part of the growing season. K fertilizer applications may be applied either as a presowing incorporation, a top dressing, or both, depending on leaching potential.

LITERATURE CITED

Aldhous, J. R. 1975. Nursery practice. Forestry Commission Bull. No. 43, Her Majesty's Stationery Office, London. 184 p.

Armson, K. A. 1960. White spruce *(Picea glauca* [Moench]Voss) seedlings: the growth and seasonal absorption of N, P, and K. University of Toronto, Forestry Bull. 6, 37 p.

Armson, K. A. and V. Sadreika. 1979. Forest tree nursery soil management and related practices. Ontario Min. of Nat. Res., Toronto. 179 p.

Landis, T. D. 1985. Mineral nutrition as an index of seedling quality. p. 29-48 IN: M. L. Duryea (ed.). Proceedings: Evaluating Seedling Quality: principles, procedures, and predictive abilities of major tests. Workshop held Oct. 16-18, 1984. Forestry Res. Lab., Oregon State Univ., Corvallis.

Powers, R. F. 1974. Evaluating fertilizer programs using soil analysis, foliar analysis and bioassy methods. p. 124-151 IN: Service-wide Work Conf. Proc., Sacramento, CA, USDA-Forest Service, Div. Timber Management, Washington, DC.

Stoeckeler, J. H. and H. F. Arneman. 1960. Fertilizers in forestry. Adv. in Agronomy 12:127-195.

Stoeckeler, J. H. and P. E. Slabaugh. 1965. Conifer nursery practice in the prairie-plains. USDA Forest Service, Agr. Handbook 279, 93 p.

van den Driessche, R. 1984a. Relationship between spacing and nitrogen fertilization of seedlings in the nursery, seedling mineral nutrition, and outplanting performance. Can. J. For. Res. 14:431-436.

van den Driessche, R. 1984b. Response of Douglas-fir seedlings to phosphorus fertilization and influence of temperature on this response. Plant and Soil 80:155-169.

van den Driessche, R. 1984c. Soil fertility in forest nurseries. IN: M. L. Duryea and T. D. Landis (eds.). Forest nursery manual: Production of Bareroot Seedlings. Martinus Nijhoff/Dr. W. Junk, The Hague.

van den Driessche, R. 1980. Health, vigor, and quality of conifer seedlings in relation to nursery soil fertility. p. 100-120. IN: Proc. North American Forest Tree Nursery Soils Workshop, held July 28-August 1, 1980 at Syracuse, NY, State University of New York, College of Environmental Science and Forestry, Syracuse.

Youngberg, C. T. 1984. Soil and tissue analysis: tools for maintaining soil fertility. p. 75-80. IN: M. L. Duryea and T. D. Landis (eds.). Forest Nursery Manual: Production of Bareroot Seedlings. Martinus Nijhoff/Dr. W. Junk, The Hague.

Soil Mapping and Testing[1]

RANDY SELIG[2]

To manage a modern forest tree seedling nursery properly, one needs some knowledge of the soil resource and its variation within the nursery. A soils map fulfills this need, and enables managers to utilize the resource effectively. Soils maps help nursery managers delineate locations where limiting factors such as shallow depth, poor drainage, salt slicks, or the presence of stones impair crop growth. A soils map is the basis for all soil sampling. Soil nutrient content measured in these samples gives some basis for annual fertilizer prescriptions.

SOIL MAPS

Types of Maps

Soil maps prepared by the Soil Conservation Service are available for much of the private land in the United States. These maps delineate soil series as they vary over the landscape. Auxiliary S.C.S. materials describe the specific properties and uses of each soil series. The usual range of surface textural class will tell one generally the various proportions of sand, silt, and clay in the different mapping units. Other properties described include soil depth, texture, pH, presence of stones, layers that restrict crop growth, drainage class, and agricultural suitability.

Most maps prepared by the S.C.S. are not very detailed. It is possible to have a more intensive survey completed by the S.C.S. or by consulting soil scientists. Some nurseries have taken samples or field-textured their soils in grid patterns as close as 100 feet by 100 feet. This is a time-consuming procedure that may not be necessary at sites that are reasonably homogeneous.

Samples generated during the mapping process should be either sent to a lab for particle size analysis or field textured to determine textural class. These same samples could also be analyzed for such basic chemical properties as organic matter (OM), cation exchange capacity (CEC), or pH. Maps of these chemical properties will assist in planning future amendment programs and annual fertilizer prescriptions.

Map Uses

One of the greatest benefits of a S.C.S. map or other textural class map is that it helps us see the variation in the soil resource. Different textural class soils have inherently different fertilities and retain nutrients differently. A good map will guide our sampling schemes so that different soils are sampled separately for nutrient analysis. Table 1 shows average values for three chemical properties of eight sandy loam fields and five clay loam fields at the Colorado State Forest Service Nursery. The sandy loams at this nursery had consistently lower pH, lower CEC's and less organic matter than did the clay loam fields. A good soil map will help keep these soils separate when sampling for nutrient analysis so that nutritional differences are not blurred.

TABLE I

SOIL TEST RESULTS FROM COLORADO STATE FOREST SERVICE NURSERY

	pH	OM	CEC
		-%-	meg/100g
SANDY LOAM[1]	7.3	2.2	11.7
CLAY LOAM[2]	8.3	3.1	17.0

[1]Ave. of 8 fields

[2]Ave. of 5 fields

SOIL TESTING

Sampling

Knowing the physical properties of the soil resource helps us sample similar soils together and improves the quality of samples taken for chemical analyses. In order to take a representative sample of each sampling unit, we need to follow several procedures carefully. For a detailed description of soil sampling procedures, please refer to F. M. Solon's paper in the Proceedings of the North American Forest Tree Nursery Soils Workshop or to Walsh and Beaton (1973).

[1]Paper presented to the Intermountain Nursery Association meeting August 13-15, 1985, Fort Collins, CO.

[2]Randy Selig is Nursery Soils Specialist for D. C. Phipps State Nursery in Elkton, OR.

Soil samples should be composite samples which are representative of a homogeneous area. Many subsamples are taken, mixed, and sometimes subsampled again. Bulking a large number of samples in this fashion reduces the effect that individual sample variation will have giving an average or mean value. Some soil scientists recommend traversing a sampling area in a large "W" taking samples along all four sides of the "W". Two W's superimposed, one upside-down on the other would represent a very thorough sampling pattern.

One composited sample can be taken for every acre or for several homogeneous acres depending on the soil's variability. Larger sampling areas need more sample cores to adequately represent that area. At least 12 cores should be taken even for an area one acre in size.

Nurseries should divide their fields into sampling areas. A 12-acre field might be divided into three to six sample areas which are internally homogeneous with respect to textural class and organic matter content. Every rotation when this field is sampled for nutrient analysis, samples would be taken from the same sampling areas as in previous years. This procedure enables nursery managers to compare soil tests from different years and to detect long-term trends such as changes in pH or OM.

There is a seasonal variation in some soil chemical values which may be of sufficient magnitude to make comparisons between samples of the same site taken at different times of the year meaningless. The exact time of year samples are taken is less important than consistently sampling in the same season year after year. Sampling sometime after seedling harvest works well if results come back from the laboratory in sufficient time to order fertilizer for the next rotation. If soil pH needs to be modified, early sampling will prove helpful by allowing time for incorporation and reaction to take place before sowing the next seedling crop. Other nurseries sample in late summer before or after fumigation because the soils are well-worked, and it is easy to obtain a good sample.

Laboratory Selection

There are many good laboratories available to analyze soil samples. Finding a good lab and staying with it will help reduce the variation in the results which could be caused by laboratories using different procedures. A good laboratory will run standard samples of soil with each batch of test samples processed. If the standard sample does not test in the accepted range for that sample, the whole batch of samples will be redone. Nurseries can double-check their lab by always sending in the same 'dummy' sample whose chemical contents are known and checking to make sure the results are in the proper range.

Soil Tests

Soil tests are not a measure of total nutrient elements but give us a chemical index of extractable nutrients which may or may not be plant available. Agronomists in a given region can often tell farmers what quantities of fertilizer to add to a certain soil 'type' to achieve a target yield of corn or wheat. This information does not exist for forest seedlings because of the diversity of nursery soils and vast array of species grown. Although most labs are not qualified or are unable to tell nursery managers how to fertilize their crop, the soil tests results are still of value. Nursery managers need to develop a recordkeeping system that will enable them to correlate soil tests with crop production.

Some standard values for soil nutrient levels have been published (Youngberg, 1984; van den Driessche, 1984; van den Driessche, 1980). Most of the available guidelines are for high rainfall areas and are not strictly usable in areas of lower rainfall and higher pH. Since soils at different nurseries seldom share common genetic or mineralogic development, it would be unfair to expect all sites to test or respond the same. Field plot experiments with two fertilizer rates and a control can add insight as to appropriate fertilization regimes and corresponding soil test values.

Nitrogen

Although N is the most commonly added fertilizer element, it is seldom prescribed through inspection of soil tests results. Tests for total nitrogen (TN) primarily indicate the amounts of organic nitrogen that are present since the inorganic fraction is small and dynamic. A test for organic matter (OM) might supply the same information indirectly since C/N of organic materials and soils is fairly constant in sites without large inputs of organic materials.

Other soil tests analyze for the main inorganic forms of mineral N, nitrate (NO_3-) and ammonium (NH_4+). Since most nurseries probably add sufficient irrigation water to leach the inorganic N out of the seedling root zone, these tests are of limited utility. Fertilizer nitrogen rates are most commonly determined by experimentation.

Phosphorus

Most soil tests for available P are quite reliable. Different procedures are used depending on the acidity or alkalinity of the soil. There is no one soil test value all nurseries should try to achieve. The chemistry of P availability is quite complex and is highly pH dependent so that different types of soil could supply adequate P at very different test levels. In most cases, it is highly advisable to add some P before sowing because small seedlings have a very large need for P before they become mycorrhizal. Since P does not move readily in the soil profile, the entire P supply for a 2+0 rotation should be incorporated shortly before sowing. Some nurseries have very low P concentrations and need to apply large quantities of P fertilizer. Other nurseries have

high P soil test values from years of heavy fertilization and only need to add smaller quantities of P fertilizer. The most desirable procedure would be to band small amounts of granular P fertilizer below the seed at sowing. Drills with fertilizer attachments do not seem to be available yet.

Exchangeable Bases

The majority of cations in any soil system are generally the bases potassium (K), calcium (Ca), and magnesium (Mg). These three are referred to as exchangeable bases and are determined in the same soil extract. Most soils in the arid and semi-arid west with near neutral or higher pH have adequate Ca and Mg. Potassium may or may not be adequate and should be maintained above 200 ppm. If the sum of the exchangeable K, Ca, and Mg exceeds the total cation exchange capacity, one should also test for electrical conductivity (sometimes called soluble salts) and for free calcium carbonate ($CaCO_3$).

pH

pH is a dynamic soil property which should be routinely determined before sowing. pH exerts a controlling influence on nutrient availability so that maintenance of pH in the proper range is of great importance. Conifer seedlings are quite sensitive to high pH, usually preferring a range from five to six. Hardwoods are more tolerant of high pH and some species can be successfully grown at pH values over seven.

Soils with pH values greater than 7.5 should also be tested for free calcium carbonate; soils with pH's greater than eight should be tested for the presence of exchangeable sodium (Na) and for electrical conductivity (EC). Both free $CaCO_3$ and Na will interfere with nutrient absorption for most forest tree seedlings. Sites with these conditions whould be avoided if possible because their amelioration is costly and time consuming.

Organic Matter

The organic content of a soil is determined by climate, topographic position, soil texture, and cropping practices. Most nursery soils slowly decrease in organic matter due to soil removal in harvest and frequent tillage. A toil test for organic matter (OM) done every rotation may indicate such a trend and its magnitude.

Nurseries with aggressive amendment programs may be forestalling the decline in OM which comes with tillage, erosion, and harvest losses. For these nurseries a carbon-nitrogen ration (C/N) determined by the laboratory in conjunction with the OM tests can be helpful in determining if the amendment is adequately broken down or if more N is necessary to help decompose the C. C/N greater than 25 or 30 might indicate a need for additional N.

Seedling Nutrient Analysis

In contrast to soil tests which tell us 'extracted' nutrients, seedling nutrient analysis (SNA) is a direct indicator of available nutrients. Seedling nutrient analysis tells one the total nutrients the seedling contain usually expressed as a concentration, either percent or ppm. Unfortunately, many biotic and abiotic factors such as drainage, compaction, temperature, microrganisms, etc., conspire to decrease the uptake or availability of soil nutrients which may be present in adequate quantities in the soil. These factors complicate the interpretation of SNA.

Sampling

Seedling nutrient content changes radically as seedlings grow and mature. Most experts recommend sampling during the time of year when values are most stable. For evergreen species, this stable 'plateau' usually coincides with deep dormancy in mid-winter. Foliate analysis is used extensively with deciduous fruit trees; these leaves are usually sampled after leaf expansion has finished in July or August. Samples should be transported to the lab immediately.

Interpretation

Analysis of seedlings with extreme nutrient deficiencies may not yield meaningful results when sampled during the dormant period. The lack of one nutrient element will have altered seedling physiology making all the nutrients out of balance. Interpretation of these numbers as in the case of alkaline soil induced iron deficiency is impossible. Sometimes better foliage analysis results can be obtained by sampling tissue at the first sign of deficiency symptoms. Comparison of paired samples of symptomatic and asymptomatic seedlings may reveal an incipient shortage of some nutrient which could be supplied by additional fertilization.

Standard values for seedling nutrient content can be found in some review articles such as those cited in the bibliography. Most of the published work relates to Douglas-fir and other important timber species. Specific values for windbreak species and less important timber crops are hard to find. A few general guidelines for minimum nutrient content can be excerpted from the literature. For instance, N almost always ranges between one and two percent, P should be at least 0.15 percent, and most species accumulate at least 0.5 percent K.

Bibliography

1. Solon, F. M. 1980. "Soil and plant tissue techniques for tree nurseries." Pages 228-235 in: Proc. North American forest tree nursery soils workshop (L. P. Abrahamson and D. H. Bickelhaupt, eds.). State Univ. New York, Coll. Environ. Sci. and Forestry.

2. van den Driessche, R. 1984. "Soil fertility in forest nurseries." Pages 63-74 in: Forest Nursery Manual (Mary L. Duryea and Thomas D. Landis, eds.). Forest Research Laboratory, OSU, Corvallis, OR.

3. van den Driessche, R. 1980. "Health, vigour, and quality of conifer seedlings in relation to nursery soil fertility." Pages 100-120 in: Proc. North American forest tree nursery soils workshop (L. P. Abrahamson and D. H. Bickelhaupt, eds.). State Univ. New York, Coll. Environ. Sci. and Forestry, Syracuse.

4. Walsh, L. M. and James D. Beaton. 1973. Soil testing and plant analysis. Soil Science Society of America, Inc., Madison, WI.

5. Youngberg, Chet. 1984. "Soil and tissue analysis: tools for maintaining soil fertility." Pages 75-80 in: Forest Nursery Manual (Mary L. Duryea and Thomas D. Landis, eds.). Forest Research Laboratory, OSU, Corvallis, OR.

How to Maximize Efficiency of Fertilizers in a Forest Tree Nursery[1]

Ivor K. Edwards[2]

Abstract

The essentiality of nitrogen, phosphorus, and potassium was reviewed. Knowledge of the reaction of these nutrients in soil is a prerequisite to efficient use of nitrogen, phosphorus, and potassium fertilizers in forest nurseries. Notwithstanding economic considerations, biological requirements are strong determinants of nursery fertilization procedures.

INTRODUCTION

In order to maximize the effects of fertilization in a bareroot tree nursery, it must be realized that nutrition like temperature, moisture, light energy, and soil factors, strongly influences plant growth and development. It is necessary to know the characteristics of nutrient elements, their function in the plant, the form in which they are preferentially absorbed by tree species, properties of the chemical compounds that are being applied, and the interaction of fertilizer products with different soils. Although there are six major and six minor elements that are essential for plant growth, the scope of this report is confined to a discussion of those most common in commercial fertilizers, namely nitrogen (N), phosphorus (P), and potassium (K). In order to optimize a tree nursery operation, it is also necessary to apply the fertilizers cost effectively. Fertilizers differ in cost throughout North America depending on the cost of their various components. Application costs will be discussed in the context of bareroot seedling production in the Canadian Prairies.

CHARACTERISTICS OF NUTRIENTS

Nitrogen: Function in Plants

Nitrogen moves readily in plants and is a mobile element in the soil. It is absorbed most commonly as nitrate (NO_3^-) and ammonium (NH_4^+) ions and less so as urea ($(NH_2)_2CO$). Within the plant, all forms of nitrogen are converted initially to the amide (NH_2) form and later combine with carboxyl groups to form amino acids, the building blocks of proteins (Tisdale and Nelson 1966). Nitrogen is an integral part of the chlorophyll molecule. Adequate N produces vigorous vegetative growth with deep green color whereas stunted chlorotic plants result from a deficiency of N. Deficiency symptoms appear first on older foliage because N is readily translocated to the meristematic region. At suboptimal levels of N, carbohydrates are deposited in vegetative cells but are converted to proteins as N increases. Excess N causes succulence and results in weakening of cell walls. The vegetative phase is prolonged and maturity is delayed, predisposing the crop to frost and insect damage.

Fate of Fertilizer N in Soil

Nitrate - NO_3

Fertilizer N exists in one or more of three forms, namely nitrate, ammonium, and urea. Nitrate nitrogen is mobile in soil and is subject to loss by leaching predominantly because it moves readily with soil water. Nitrate is not strongly held on the soil exchange complex because of its negative charge. Thus, irrigation and the presence of coarse textured soils (a combination common in many bareroot tree nurseries) lead to leaching loss of nitrate from the root zone.

Since nitrate moves readily with soil water, it also moves upwards with capillary water during dry weather and may be deposited in surface or near surface soil horizons following evaporation.

Nitrate is lost also through denitrification by bacterial conversion to ammonium N and eventually to gaseous N (volatilization). Poor

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drainage, impaired soil oxygen, and alkaline conditions contribute to denitrification.

Nitrate N is subject to assimilation by soil microorganisms especially in the presence of organic material with a high carbon:nitrogen ratio such as sawdust. N is released only when the microbial activity declines.

Ammonium - NH_4

The primary reaction of the NH_4^+ ion is nitrification whereby ammonium N undergoes bacterial conversion to nitrate. Warm (30°C), moist (field capacity), and well aerated soils accentuate nitrification. Ammonium N is subject also to immobilization by microorganisms in the presence of organic material of high C:N ratio. Nitrogen is released through mineralization only when microbial activity declines as the energy source of the bacteria is depleted. Therefore, if organic material with a wide C:N ratio such as grain straw or sawdust, is added to nursery seedbeds, sufficient N should be added simultaneously to satisfy bacterial and plant needs.

The ammonium ion is absorbed more strongly than nitrate by soil colloids owing to its positive charge and therefore is less prone to leaching by percolating water. Its retention in soil is fostered by high cation exchange capacity, and by soil conditions that are unfavorable for nitrification, e.g., low temperature, excess soil moisture. However, conditions (waterlogging and oxygen deficiency) that favor denitrification should be avoided.

In alkaline soil, the ammonium ion is converted to gaseous ammonia and is subject to loss through volatilization. Deep placement, i.e. well within the root zone, adequate mixing, and avoidance of hot, windy conditions during application of ammonium fertilizers will minimize N loss. Ammonium fertilizers increase acidity generally because nitrification is an acid-forming process.

Urea - $(NH_2)_2CO$

In soil, urea reacts with water, i.e., hydrolyzes, to form initially ammonium carbonate and subsequently free ammonia, ammonium ions, and carbonate ions. The initial hydrolysis is aided by the enzyme urease and because it is rapid, seedlings may be damaged by the ammonia released. Nitrogen loss through volatilization is minimized by deep placement. However, fate of the ammonium ion, once formed, will be controlled by plant uptake and factors that affect nitrification and immobilization as explained earlier. The immediate effect of urea fertilizer is to increase soil pH but as nitrification progresses, pH is reduced.

Nitrogen Forms and Seedling Growth

Among conifers, the preferred form of N varies with tree species. In Saskatchewan, 3-0 jack pine (Pinus banksiana) produced best growth in terms of height and dry weight with either ammonium sulphate or calcium nitrate (Edwards 1981). White spruce (Picea glauca) on the other hand grew best with ammonium N. In British Columbia, Douglas-fir (Pseudotsuga menziesii) grew best with the ammonium form of N (van den Driessche 1984).

It should be pointed out that soil properties play an important role in maximizing the efficiency of applied N. Since ammonium fertilizers are acid forming, they promote uptake of N in soils in which soil pH is unsuitably high. Ammonium sulphate, for example, is prescribed repeatedly in Western Canada for circum-neutral soil in bareroot nurseries.

Nitrate fertilizers, excluding ammonium nitrate, are not acid forming but could raise soil pH. Use of nitrates of sodium, potassium and calcium may result in alkaline conditions; mobile nitrate ions are readily absorbed by plants leaving an excess of basic cations.

Phosphurus: Function in Plants

Phosphorus is absorbed in lower amounts than either N or K, but it is essential for the initiation of primordial growth and seed formation and the stimulation of root growth. It acts as an energy carrier, being part of the high energy phosphate bonds that are essential in the processes of photosynthesis and respiration (Tisdale and Nelson 1966). Phosphorus deficiency leads to severe stunting, and depending on the plant species, leaves could be deep green or the lower (older) leaves and needles may become deeply bronzed or reddish-purple. Sometimes there are no symptoms of P deficiency besides severe reduction in growth. It is a mobile element in plants and normally deficiency symptoms develop earliest on lower (older) tissue.

Fate of Phosphorus in Soil

Availability of P in soil depends on pH and on the presence of other ions, but efficiency of P utilization by plants is low (20%). Plants absorb P mostly as orthophosphate ions, $H_2PO_4^-$ and HPO_4^{2-}. In acid medium, $H_2PO_4^-$ is favore but the presence of aluminum, iron and manganese in very acid soil results in fixation or precipitation of P as insoluble phosphates. As soil pH rises above pH 5.0, $H_2PO_4^-$ declines in favor of HPO_4^{2-} but above pH 7.0, the presence of calcium and magnesium will result in precipitation of insoluble phosphates (Tisdale and Nelson 1966). In general, soil pH of 5.0 - 6.0 is ideal for conifers whereas pH of 6.0 - 7.0 is preferable for hardwoods.

The above fixation or loss in availability may be minimized by proper placement. Broadcast

placement followed by intimate mixing with the soil leads to increased fixation, assuming the above factors (pH, metal ions) are present. The recommended alternative is band placement whereby the fertilizer is set in localized bands beside and below the seed.

Soil-fertilizer contact may be minimized also by pelleting or aggregating the fertilizer. This is advisable with materials of high water solubility. (Slow-release fertilizers are coated with slowly soluble compounds to retard reaction of the fertilizers with soil water.) This is especially useful in areas of high precipitation). Enhanced utilization of phosphate fertilizers may be achieved also by combining them with organic matter (peat, farm manure, etc.) to extend their availability.

Potassium: Function in Plants

Potassium unlike N and P is not synthesized into other compounds. It is absorbed as the ion K^+ and is essential for protein synthesis and in production and translocation of carbohydrates. It is related to N metabolism; K deficient plants are high in soluble N suggesting blockage in the synthesis of protein from amino acids (Tisdale and Nelson 1966). It is a mobile element; defiiency symptoms occur first on lower leaves as marginal or tip burn and in some cases as chlorosis. It also functions in the promotion of growth of meristematic tissue, strengthens cell walls and is essential to stomatal movement and control of turgor (Tisdale and Nelson 1966).

Fate of Potassium in Soil

Potassium in soil exists primarily as an unavailable (fixed) form that is in equilibrium with smaller amounts of a slowly available and readily available forms. As plants absorb readily available (i.e. water soluble and exchangeable) K, the amount absorbed is replaced from both the slowly available and unavailable forms in a reversible process and a dynamic equilibrium is maintained. Most (90-98%) of the K in soils is in the unavailable form and held by secondary clay minerals (expanding type).

When K fertilizers are applied to the soil, the element may be readily absorbed from solution, or absorbed by clays as exchangeable K. Some of the unused K reverts to the slowly available form and finally supplements the large unavailable pool. Plant uptake causes K to move slowly in the opposite direction and replenish the easily available fraction.

Potassium is subject to leaching in soil but its retention in slowly available and unavailable forms for eventual release to plants helps to minimize losses. Long term application of K fertilizers reduces the K-fixing power of the soil and increases the easily available (exchangeable) fraction. The degree of retention against leaching loss will depend on soil texture and, consequently, the exchange capacity. Many bareroot nurseries have coarse textured soils with low exchange capacity and are irrigated; such soils are more prone to leaching losses of K. Leaching loss of K increases as soil acidity increases (Krause 1965) and below pH 5.0, it is advisable to apply lime to increase the degree of base saturation and lower the risk of K loss. On neutral and alkaline nursery soils in Saskatchewan leaching loss of K was miniscule compared to that of calcium, magnesium, and NO_3-N (Edwards 1977).

Timing and Placement of Fertilizers

Efficiency of utilization of fertilizers can be increased by proper timing and placement. For production of conifer seedlings in bareroot nurseries, P and K are applied as basal dressings during preparation of the seedbed prior to seeding whereas N is applied as a top dressing in multiple doses and at two to three week intervals throughout the growing season. Nitrogen fertilizers especially NO_3 are subject to leaching loss in coarse textured soil and may cause salt injury to young seedlings. Following application, all fertilizer material should be brushed off the foliage and watered lightly into the soil. Multiple applications of N are warranted also because rate of growth and nutrient uptake vary through the season (Armson 1963). A more precise approach to multiple dosage is application of the fertilizer according to the accumulation of heat units. Armson (1962) recommended the use of 36°F (2°C) as the base temperature for white spruce in Ontario.

Although many nurseries use broadcast application of P, ideal placement is banding because of its relative immobility in soil, propensity for fixation and its low degree of recovery by plants. Banding of the fertilizer (beside and below the seed) causes less mixing with the soil and lowers the risk of fixation (Tisdale and Nelson 1966). The practice requires specialized equipment and this may account for its unpopularity in tree nurseries so far. (The technique has been applied successfully in agriculture.)

Potassium is mobile in soil and may be applied as multiple top dressings. The practice is followed in some nurseries but the primary drawback is the risk of foliar burn to seedlings. Broadcast application followed by disking prior to seeding is the practice at many nurseries in the prairie region. However in locations with soils of high K-fixing capacity, band placement is advisable.

Both N and K fertilizers lend themselves to liquid application (fertigation) because of their high solubility. The practice has been followed in only one of the prairie nurseries. Degree of nutrient availability is similar compared to solid application but more practical questions have to be considered by the nurserymen. Is soil texture very coarse? Is frequent irrigation between

fertilization events required because of hot weather? What is the strategy to be followed during extensive periods of rainy weather when the fields are due to be fertilized? A safe approach is to rely on solid material to supply the basic amount of nutrients. Supplemental amounts may then be supplied by liquid application. The effect of the latter may not be prolonged but it is useful as a quick boost where this is necessary, e.g. inclement weather.

Fertilizers Commonly Used in Nurseries

In bareroot nurseries, the most commonly used sources of N exclusively are ammonium sulfate (21-0-0) and ammonium nitrate (34-0-0). Phosphorus exclusively is supplied by ordinary superphosphate (0-20-0) and concentrated (triple) superphosphate (0-45-0). Popular combinations of N and P are the ammonium phosphates, specifically monoammonium phosphate (11-48-0 and 11-55-0), diammonium pnosphate (21-54-0), and ammonium phosphate-sulfate (16-20-0). The most common sources of K are potassium sulfate (0-0-50) and potassium chloride (0-0-62).

Rationale for the use of specific fertilizers is developed with biology and economics in mind and, depending on the circumstances, there may be trade-offs between both areas. Thus a price list (Table 1) may be important but long term viability of the nursery is of greater consequence. As a N source, ammonium nitrate is less acid than where soil pH is within acceptable limits. Ammonium sulfate is useful as an acidifying agent (along with elemental sulphur) where soil pH exceeds acceptable limits.

The ammonium phosphates by combining two elements help to lower handling and shpping costs per unit of nutrient. The high nutrient concentration of compounds such as diammonium phosphate adds to their attractiveness. The superphosphates are neutral (to soil pH) and the high P concentration adds to handling efficiency. The drawback with concentrated superphosphate is its uncertain availability and like other phosphate products (in Western Canada) is expensive (Table 1). Among phosphate sources monoammonium phosphate (11-55-0) was shown to be most effective for Douglas-fir (van den Driessche 1984). Monoammonium phosphate (11-48-0) was also found to be effective for white spruce (Edwards 1981).

The choice of potassium source should be governed by the prevailing salinity level in the soil and irrigation water and the ease with which the soil can be leached. Normally, in western Canadian nurseries if electrical conductivity of the soil exceeds 1.0 mS/cm and that of irrigation water exceeds 0.75 mS/cm, potassium sulfate is preferred. Potassium chloride has a greater salt index and therefore a greater potential for salinity problems and chloride toxicity.

Table 1: Cost (Can.$)[1] of selected fertilizers in western Canada in 1985

Formulation	Fertilizer $/tonne[2]	N $/kg	P $/kg	K $/kg
21-0-0	217	1.03	---	---
34-0-0	263	0.77	---	---
46-0-0	300	0.65	---	---
11-51-0	425	3.86	1.89	---
16-20-0	318	1.99	3.61	---
0-20-0	390	---	4.43	---
0-45-0	600	---	3.03	---
0-0-50	356	---	---	0.86
0-0-62	175	---	---	0.34

[1]Canadian $1.00 is equivalent to U.S. $0.70 approximately

[2]Includes transportation charges and represent random sampling over three prairie provinces.

SUMMARY

The major elements N, P and K are essential to proper plant growth and play a most important role in the constitution of chemical fertilizers that are commonly applied in tree nurseries. In order to use the fertilizers most efficiently, it is necessary to know how each element reacts with the soil following application and the factors that affect their uptake by plants. These considerations will determine optimum timing and placement of the fertilizer. Cost and availability of fertilizers affect selection of specific materials but biological concerns ought to be given priority.

LITERATURE CITED

Armson, K. A. 1962. The growth of white spruce seedlings in relation to temperature summation indices. For. Chron. 38:439-444.

Armson, K. A. 1965. Seasonal patterns of nutrient absorption by forest trees. p. 65-75. In Forest Soil Relationships in North America, C. T. Youngberg Ed. Papers presented at the Second North American Forest Soils Conference, Oregon State University, Corvallis, OR August 1963. 532 p.

Edwards, I. K. 1977. Nutrient movement in a sandy loam forest nursery soil at Prince Albert, Saskatchewan. Can. For. Serv., Nor. For. Res. Cent., Inf. Rep. NOR-X-195.

Edwards, I. K. 1981. Soil amendments and fertilizers improve bareroot seedling growth in tree nurseries. p. 7-10. In Forestry Report. J. Waldron and J. Samoil editors. Can. For. Serv., Nor. For. Res. Cent. For. Rep. No. 24. Edmonton, Alberta 16 p.

Krause, H. H. 1965. Effect of pH on leaching losses of potassium applied to forest nursery soils. Soil Sci. Soc. Am. Proc. 29: 613-615.

Tisdale, S. L. and W. L. Nelson. 1966. Soil fertility and fertilizers. Second edition. 694 p. Macmillan Company, New York.

van den Driessche, R. 1984. Response of Douglas-fir seedlings to phsophorus fertilization and influence of temperature on this response. Plant and Soil 80:155-169.

Cold-Hardiness Testing of Conifer Seedlings[1]

Karen E. Burr, Stephen J. Wallner, and Richard W. Tinus[2]

Abstract.--This paper briefly describes the results of preliminary experiments designed to test four objective methods of rapidly predicting cold hardiness of conifer seedlings; differential thermal analysis, ethylene evolution, and freeze-induced and heat-induced electrolyte leakage.

INTRODUCTION

We are testing four objective methods of rapidly predicting cold hardiness of conifer seedlings; differential thermal analysis, ethylene evolution, and freeze-induced and heat-induced electrolyte leakage. This information will be used as a research tool to optimize hardening regimes and as a management tool to reduce losses associated with the timing of removal of seedlings from the greenhouse, cold storage, and outplanting.

DIFFERENTIAL THERMAL ANALYSIS (DTA)

DTA of buds is one approach for those species that supercool, such as the spruces and Douglas-fir. The cold hardiness of these species is related to their capacity for supercooling, and the extent of that supercooling is measured by DTA.

The DTA profile of a cold hardy bud that supercools (fig. 1) has two peaks or exotherms which are formed when heat is released by the freezing of water within the bud. The first exotherm represents freezing of extracellular water which generally causes no injury to the bud. The low temperature exotherm (LTE) represents freezing of supercooled intracellular water and is associated with lethal injury (Sakai 1978). The DTA profile of a cold hardy bud from a species that does not supercool, such as any of the pines, has a first exotherm but no LTE and is thus of no diagnostic value. The temperatures at which LTE's occur in buds that supercool are well correlated with bud acclimation and deacclimation to cold (fig. 2) and with concurrent changes in whole plant condition (fig. 3).

Concerns about bud sampling for DTA are eased by the relatively low variability of LTE temperatures among buds of individual cold hardy trees (figs. 4 and 5). However, extremely small buds do not provide reliable DTA data (fig. 6). Minimum fresh weight guidelines were set at 2.8 mg for Douglas-fir buds and 1.2 mg for Engelmann spruce buds. Position on the tree had no significant effect on LTE temperature for buds of adequate size on fully cold hardy trees.

Three other approaches for predicting cold hardiness are under consideration, since pines do not supercool and buds are not always present on those species that do.

ETHYLENE EVOLUTION

A seasonal pattern of ethylene production has been observed in white pine (Seibel and Fuchigami 1978). Ethylene levels were highest in spring

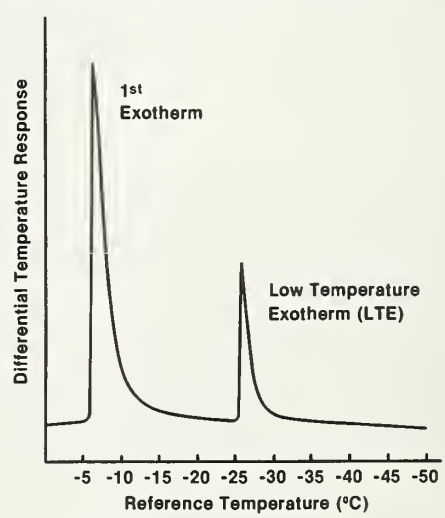

Figure 1.--DTA profile of a cold hardy bud that supercools.

[1]Poster presented at the Intermountain Nurseryman's Association Meeting. [Fort Collins, Colo., August 13-15, 1985].

[2]The authors are, respectively: Graduate Research Assistant, Department of Horticulture, Colorado State University, Fort Collins, Colo.; Professor of Plant Stress Physiology, Department of Horticulture, Colorado State University, Fort Collins, Colo.; Project Leader, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Forestry Sciences Lab., Flagstaff, Ariz.

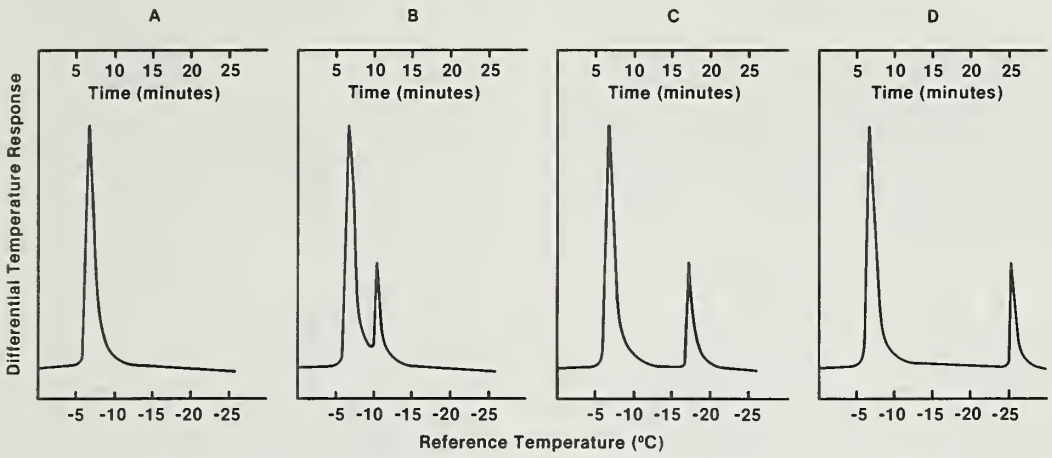

Figure 2.--Acclimation of buds that supercool, as indicated by LTE temperature. The reverse occurs with deacclimation.
A. Non-acclimated. The single exotherm represents freezing of all tissue water which results in injury.
B. Early acclimation. The capacity for supercooling has developed.
C. Moderately cold hardy. LTE temperatures become progressively lower with increasing cold hardiness.
D. Fully cold hardy. Bud LTE's at -25° C commonly occur in fully cold hardy Engelmann spruce grown in Colorado.

during active growth, declined to low levels in fall with vegetative maturity, and were not detectable during winter. Preliminary investigation using gas chromatography suggests this pattern may also exist in ponderosa pine, but it is not likely to occur in Douglas-fir or Engelmann spruce (fig. 7).

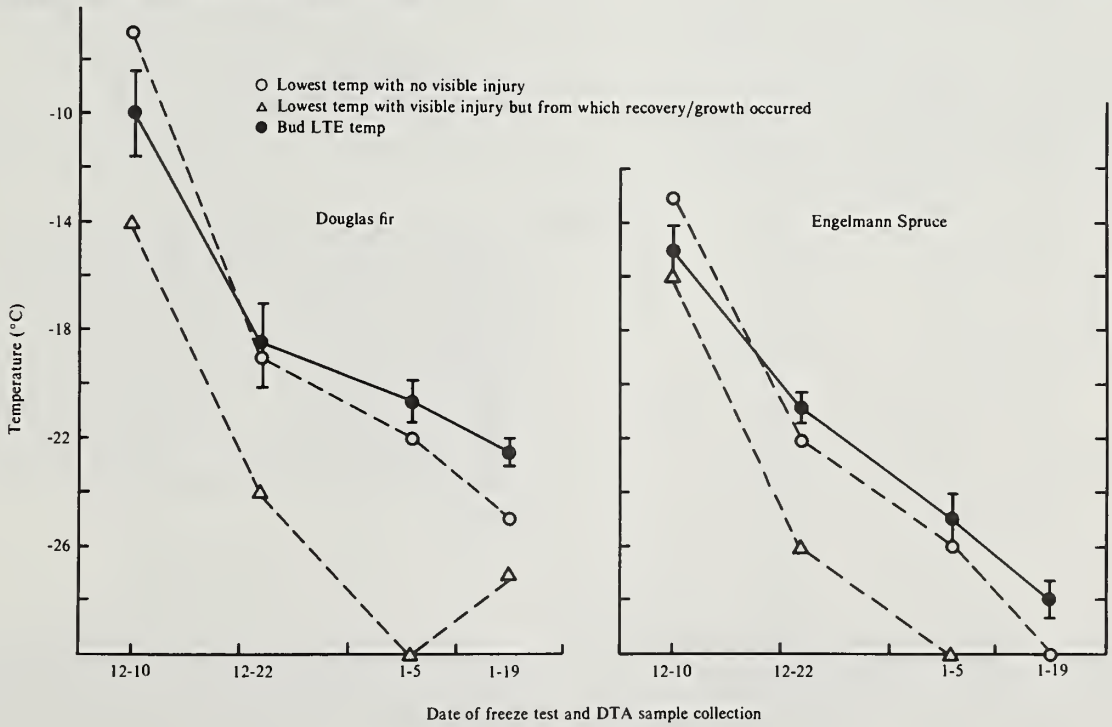

Figure 3.--Comparison of bud LTE temperatures and the results of whole plant freezing tests (Tinus et al. 1985).

ELECTROLYTE LEAKAGE

Plant hardiness with respect to temperature stresses which, when injurious, cause disruption of cell membranes and the subsequent leakage of cell contents, can be quantified by measuring the amount of electrolytes which leak from the plant tissue following exposure to a given stress. Electrolyte leakage is reported as percent index of injury, calculated by the formula

$$1 - \frac{1-(T_1/T_2)}{1-(C_1/C_2)} \times 100$$

where T_1 and T_2 are the conductivity of the treatment solution before and after boiling, respectively, and C_1 and C_2 are the conductivity of the control solution before and after boiling, respectively (Flint et al. 1967). A lower percent index of injury indicates greater hardiness.

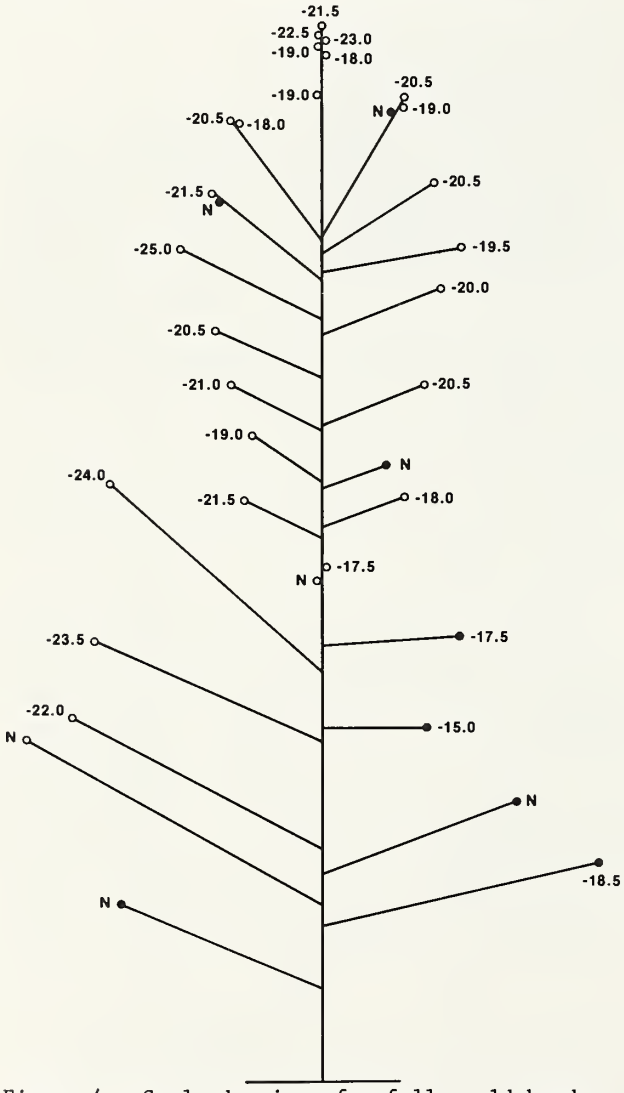

Figure 4.--Scale drawing of a fully cold hardy, 2-year-old, container grown Douglas-fir seedling 33.2 cm tall. LTE temperatures are in °C for each bud. Mean LTE temperature, ± 1 standard deviation, is -20±1.5° C. 'N' indicates no reliable LTE detected.
- ● Bud fresh weight <2.8 mg
- o Bud fresh weight ≥2.8 mg

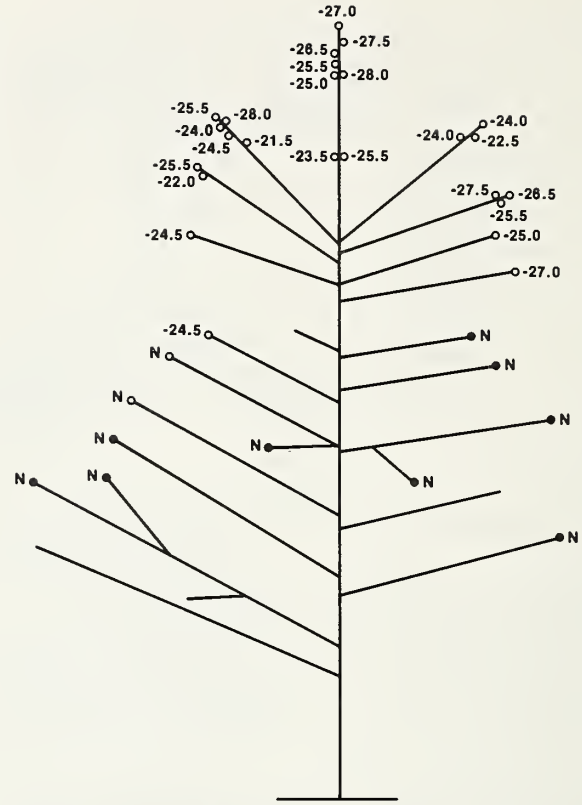

Figure 5.--Scale drawing of a fully cold hardy, 2-year-old, container grown Engelmann spruce seedling 24.5 cm tall. LTE temperatures are in °C for each bud. Mean LTE temperature, ± 1 standard deviation, is -25±2.8° C. 'N' indicates no reliable LTE detected.
- ● Bud fresh weight <1.2 mg
- o Bud fresh weight ≥1.2 mg

Freeze Induced

Electrolyte leakage from Douglas-fir needle tissue following in vitro freezing stress was measured on samples taken at 16 intervals throughout a 152-day, growth chamber controlled, cold hardening and deacclimation regime to produce the series of curves in figure 8. Seven test temperatures were selected at each interval to produce each individual curve. Precise testing procedures enable the detection of fairly small changes in cold hardiness over time. Similar series of curves have been produced for ponderosa pine and Engelmann spruce.

Heat Induced

The changes which confer cold hardiness also result in greater heat tolerance for certain species (Levitt 1980). Electrolyte leakage from needle tissue following in vitro heat stress was measured to assess the possibility of this occurring in conifers. Results for ponderosa pine were opposite those for Douglas-fir and Engelmann spruce (fig. 9).

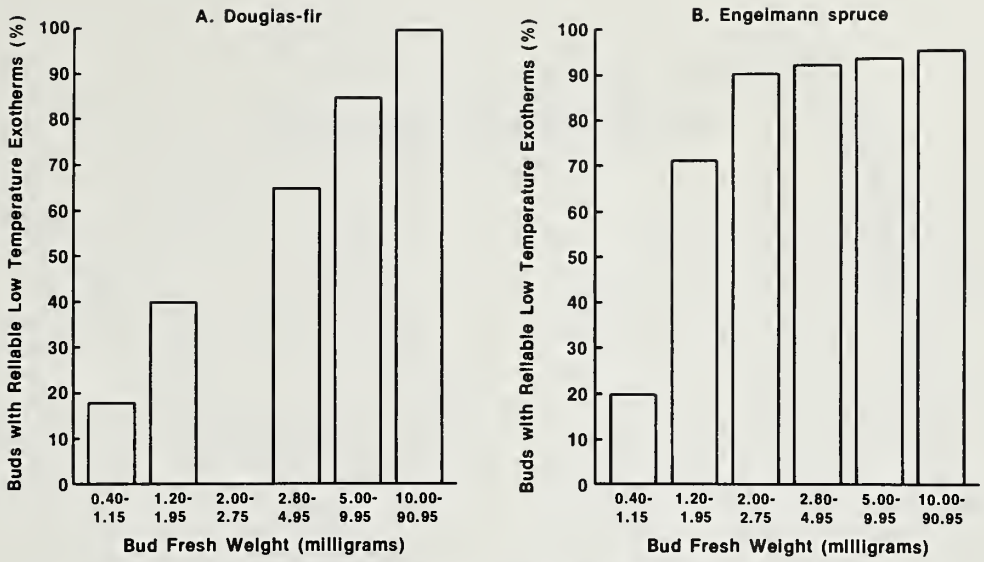

Figure 6.--Percentage of buds from cold hardy seedlings with reliable LTE's by bud fresh weight.

FUTURE RESEARCH

Extensive whole plant freezing tests are being conducted to calibrate each of the four quick tissue tests and to determine how well these tests predict cold hardiness. These results are also being compared with measurements of dormancy and root growth capacity.

LITERATURE CITED

Flint, H. L., B. R. Boyce, and D. J. Beattie. 1967. Index of injury--A useful expression of freezing injury to plant tissues as determined by the electrolytic method. Canadian Journal of Plant Science 47:229-230.

Levitt, J. 1980. Responses of plants to environmental stresses. Volume 1. Chilling, freezing and high temperature stresses. Academic Press, N.Y.

Sakai, A. 1978. Low temperature exotherms of winter buds of hardy conifers. Plant and Cell Physiology 19:1439-1446.

Seibel, J., and L. Fuchigami. 1978. Ethylene production as an indicator of seasonal development in red-osier dogwood. Journal of the American Society for Horticultural Science 103(6):739-741.

Tinus, R. W., J. E. Bourque, and S. J. Wallner. 1985. Estimation of cold hardiness of Douglas-fir and Engelmann spruce seedlings by differential thermal analysis of buds. Annals of Applied Biology 106:393-397.

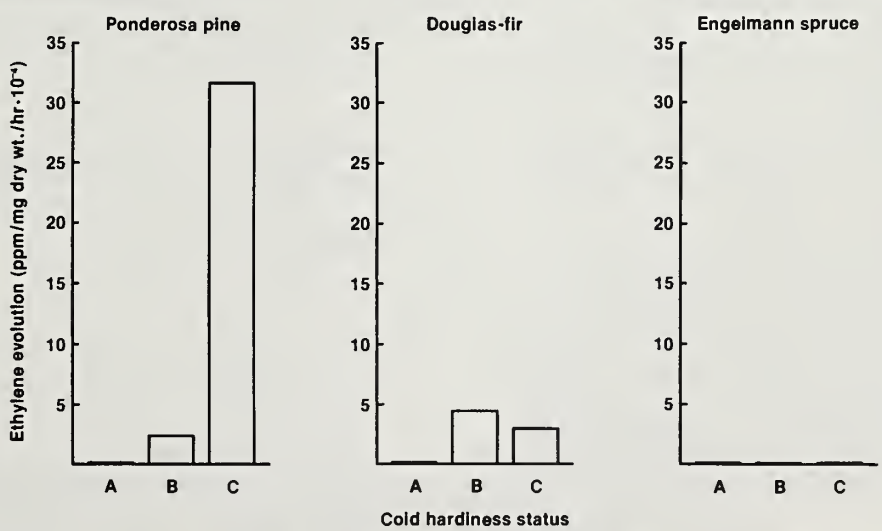

Figure 7.--Ethylene evolution from needle samples of three species at varying levels of cold hardiness: (A) fully cold hardy, (B) early cold deacclimation, (C) actively growing.

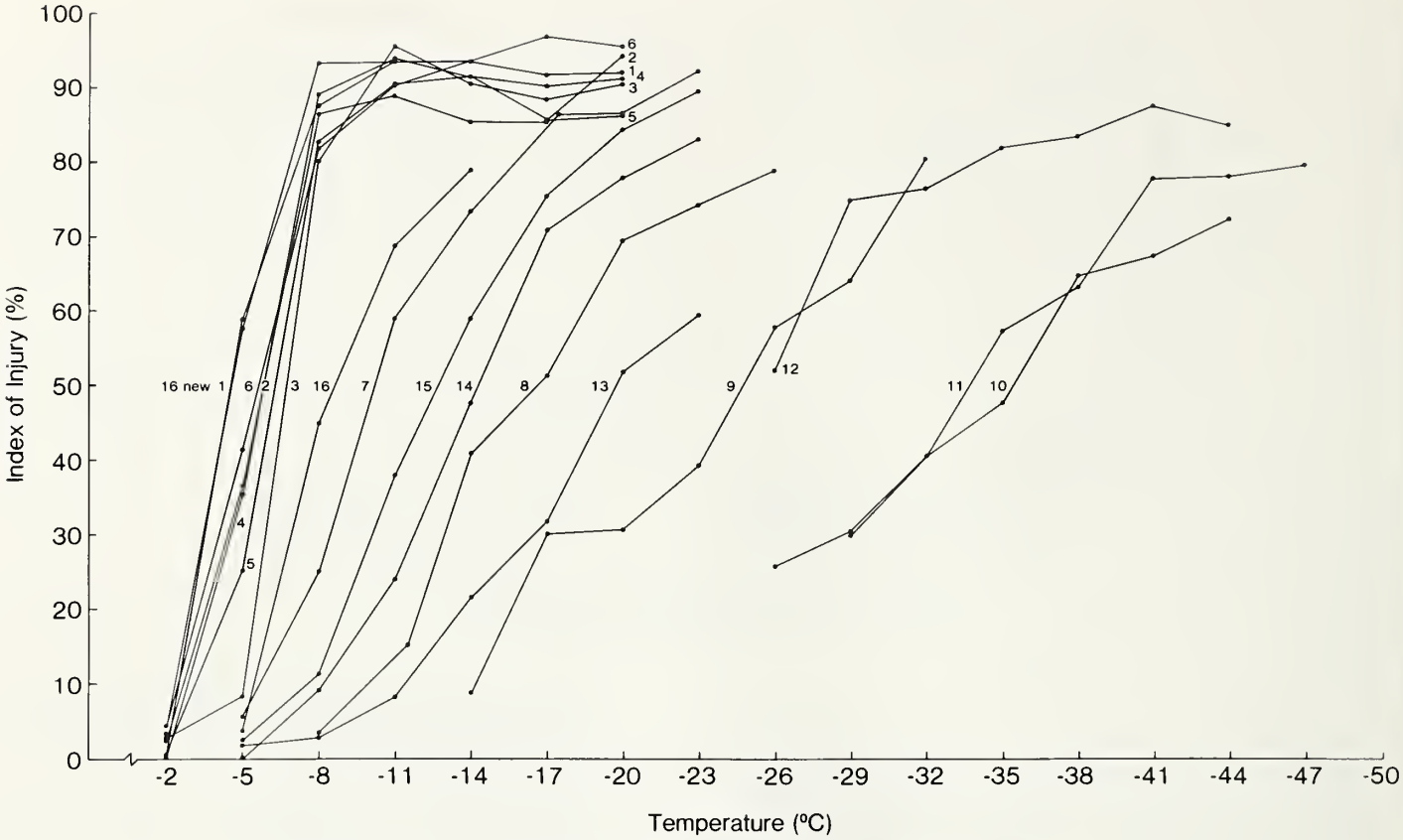

Figure 8.--Index of injury following in vitro freezing stress of Douglas-fir needles sampled at intervals throughout a cold hardening and deacclimating regime. The hardening portion of the regime began with actively growing seedlings represented by curve 1 and ended 111 days later with fully cold hardy seedlings represented by curve 11. The deacclimation period began on the 112th day and includes curves 12 through 16. The previous season's growth and the new growth were both tested on the completely deacclimated, actively growing seedlings on the 152nd day and are represented by curves 16 and 16 new, respectively.

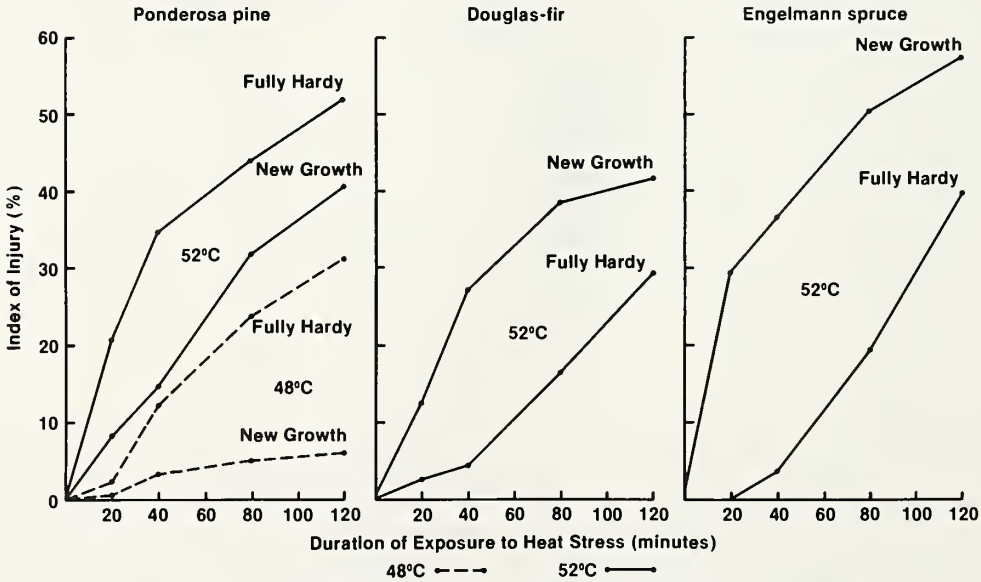

Figure 9.--Index of injury following in vitro heat stress of needle samples from actively growing and fully cold hardy seedlings of three species.

Business Meeting Notes

WHERE: Lyons Park, Lyons, Colorado

WHEN: August 14, 1985

Chairman, Marvin Strachan, called meeting to order at 1:15 p.m.

OLD BUSINESS:

Sally Johnson reported on progress for 1986 joint meeting with Western Forest Nursery Council to be held in Olympia, WA. Sally said "They're working on it!"

Al Myatt said plans for the 1987 Intermountain meeting are proceeding. It will be held in Norman, OK, and he solicited ideas for "a new twist" to the meeting. Submit your ideas in writing to Al at the Oklahoma State Nursery.

Tom Landis reported that the Proceedings from last year's meeting in Coeur d'Alene, Idaho, is out as a General Technical Report and cost $5000 to publish. Tom doesn't know how much longer the publication money will be available from the Forest Service. He said this year's proceedings will be covered in the same manner. Options for future publication, if and when the money is no longer available through the Forest Service, include: 1) Special Edition of "Tree Planter Notes." 2) Publish through the "Canadian Journal of Forest Research."

NEW BUSINESS:

Dave Simpson made a bid for 1988 joint meeting to be held in British Columbia. David Grierson offered, in the name of Utah State Lands & Forestry, to host the 1989 meeting in Utah. Offer seconded by Frank Rothe and accepted by a majority voice vote.

Randy Selig made a motion to change the name of our Association from "Intermountain Nurserymen's Association" to "Intermountain Nursery Association." Motion was seconded by Tom Landis. Motion carried on a majority voice vote.

INFORMATIONAL NOTES:

Dick Jeffers announced his investigation of the idea to create a Nursery Working Group as a part of the Forestry Committee of the Great Plains Agricultural Council. This working group would pursue nursery related research problems for the Great Plains Area. The working group would meet annually in conjunction with the Forestry Committee meeting. He will be soliciting input from us in the future.

Lee Hinds announced the International Windbreak Symposium to be held in Lincoln, Nebraska, on June 23-27, 1986. Volunteer papers are being called for and a text book (manual) for windbreak establishment and care will result from this meeting.

Jerry Grebasch made a plea for more east-west exchange of information. He expressed his appreciation for being invited to our meeting and suggested we might consider sending the Chairperson of our annual meeting to the eastern meeting as a representative of INA. No action was taken.

Lee Hinds moved to adjourn the meeting. Sally Johnson seconded. Meeting adjourned at 1:55 p.m.

Respectfully submitted by:

Jim Fischer
for the Intermountain Nursery Association.

MESSAGE AND ACKNOWLEDGEMENT FROM CHAIRPERSON

The 85 registered participants found the 25th annual meeting of the Intermountain Nursery Association not only informative but also enjoyable. Several concepts, new to the Intermountain Nursery Group, proved to be successful. The membership convened in four concurrent groups to discuss high priority topics. Each group was able to attend and participate in all four sessions. Twelve prepared papers were well presented at the formal paper session.

The tour not only observed Forest Nursery operations but also ecological conditions in the Rocky Mountain National Park area.

Special acknowledgement must be given to the commercial exhibitors who contributed financial assistance and demonstrated their products and information to the forest nurserymen. These contributors were Native Plants, Inc., Stuewe & Sons, Loveland Industries, Silva Seed, American Clayworks and the J. E. Love Company. Much credit for a successful meeting must also go to the membership who contributed much by demonstrating a high degree of interest and cooperation. We thank you all.

Marvin D. Strachan
Chairman

List of Attendees

Larry Abrahamson
State University of New York
Syracuse, New York

Lyle Alspach
PFRA Tree Nursery
Agriculture Canada
Indian Head, Saskatchewan, Canada

Amanullah K. Arbab
Tribal Forestry Department
Fort Defiance, Arizona

Jim Barnett
U.S. Forest Service
Pineville, Louisiana

Jim Borland
Denver Botanical Gardens
Denver, Colorado

Karen E. Burr
Department of Horticulture
Colorado State University
Fort Collins, Colorado

Peter Clarkson
Technical Forestry Services
Portage La Prairie, Manitoba, Canada

Tom Corse
Bureau of Indian Affairs
Polson, Montana 59860

Rodger Danielson
Oregon State University
Corvallis, Oregon

Robyn Darbyshire
Oregon State University
Corvallis, Oregon

Al deHaas
USFS, Placerville Nursery
Camino, California

Gary Dinkel
USFS, Bessey Nursery
Halsey, Nebraska

Ivor Edwards
Canadian Forestry Service
Edmonton, Alberta, Canada

Kent L. Eggleston
USFS North Central Experiment Station
Rhinelander, Wisconsin

Thomas P. Emerson
USFS
Watersmeet, Michigan

Jay Faulconer
International Paper Co.
Lebanon, Oregon

Robert J. Fewin
Texas Forest Service
Lubbock, Texas

Jim Fischer
Colorado State Forest Service
Colorado State University
Fort Collins, Colorado

Mike Gerdes
Silvaseed

Robby Gibson
Colorado State Forest Service
CSU
Fort Collins, Colorado

John Gleason
Oregon State University
Corvallis, Oregon

Jerry Grebasch
Iowa Conservation Commission
Ames, Iowa

David Grierson
Utah State Lands & Forestry
Draper, Utah

Allen C. Hackleman
CSFS, CSU
Fort Collins, Colorado

Oscar Hall
USDA Forest Service
National Tree Seed Laboratory
Dry Branch, Georgia

Roger Hamilton
Alberta Forest Service
Smoky Lake, Alta, Canada

Jill E. Handwerk
Greener 'n Ever Tree Farm
Fort Collins, Colorado

Gene Hartzell
California Department of Forestry
Davis, California

Eileen Harvey
Canadian Forestry Service
Edmonton, Alberta, Canada

Mark Harvey
Alberta Forest Service
Edmonton, Alberta, Canada

Willis J. Heron
Dept. of State Lands
Division of Forestry
Missoula, Montana

Rex Huffacre
Native Plants, Inc.

Lee Hinds
Lincoln-Oakes Nurseries
Bismarck, North Dakota

John H. Hinz
USFS Bessey Nursery
Halsey, Nebraska

Richard M. Jeffers
USDA Forest Service
Lakewood, Colorado

Sally Johnson
Seedling Quality Services
Centralia, Washington

James (Jeff) Kayler
Fantasy Farm NSY
Peck, Idaho

Mark Kettler
Technical Forestry Services
Portage La Prairie, Manitoba, Canada

Glen Killough
Texas Forest Service
Lubbock, Texas

Roy Laframboise
North Dakota Forest Service
Towner, North Dakota

Tom D. Landis
USDA Forest Service
Lakewood, Colorado

Matt Lavin
University of Texas
Austin, Texas

C.D. McAninch
USDA Forest Service
Lakewood, Colorado

Doug McCreary
Oregon State University
Corvallis, Oregon

Fred McElroy
Peninsu-Lab
Kingston, Washington

Paul McKinley
Greener 'n Ever Tree Farm
Carmel, California

Nancy K. McQuinn
Simpson Timber Co.
Arcata, California

Nancy Mikkelson
Colorado State University
Fort Collins, Colorado

Randy Moench
SD Div. of Forestry
Big Sioux Nursery
Watertown, South Dakota

Bart Mortensen
Colo-Hydro, Inc.
Longmont, Colorado

A.K. Myatt
Oklahoma Forestry Division
Washington, Oklahoma

Stan Navratil
Alberta Forestry Service
Spruce Grove, Alberta, Canada

Bruce Neill
PFRA Tree Nursery
Agriculture Canada
Indian Head, Saskatchewan, Canada

Steve Omi
Oregon State University
Corvallis, Oregon

Kent Ostler
NPI
Salt Lake City, Utah

Richard C. Ostrowski
Loveland Industries/Hopkins
Madison, Wisconsin

Joe Perry
Greener 'n Ever Tree Farm
Carmel, California

Blair Posey
LAVA Nursery
Parkdale, Oregon

Tony Ramirez
Lone Peak State Nursery
Draper, Utah

Verna Reedy
Champion Timberlands Nursery
Plains, Montana

Bob Reeves
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Loveland, Colorado

Larry Roberts
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Fort Collins, Colorado

Ed Rothe
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Longmont, Colorado

Frank Rothe
Colo-Hydro, Inc.
Longmont, Colorado

David A. Sbur
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Arcata, California

Richard M. Schaefer
Potlatch Corporation
Lewiston, Idaho

Bill Scheuner
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Camino, California

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Washington, Oklahoma

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Moscow, Idaho

Leaford Windle
USDA Albuquerque Nursery
Belen, New Mexico

Barry Wood
Pine Ridge Forest Nursery
Smoky Lake, Alta, Canada

Terry S. Yeh
USFS Cibola National Forest
Peralta, New Mexico

Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526